TRANSPORTATION RESEARCH RECORD 900

State and Local Transportation Finance and Cost Allocation

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Life-Cycle Pavement Cost Allocation

MICHAEL J. MARKOW AND THOMAS K. WONG

Past highway cost-allocation studies have relied primarily on principles of highway construction in attributing cost responsibilities among vehicle classes. However, the changing character of state and federal highway programs, which emphasizes maintenance and rehabilitation in lieu of new construction, coupled with the need for increased highway revenues prompted Congress to mandate a new cost-allocation study in 1978. As part of that effort, this research considered one key element of highways—pavements—and investigated life-cycle (i.e., maintenance and rehabilitation) costs attributable to different vehicle classes. Central to this study was the use of a simulation model of highway performance and costs that could consider variations in the several parameters of the problem. Different economic criteria were applied, which included pure efficiency (short-run marginal cost pricing) and equity-based measures. The general engineering and economic concepts used in this approach and results of several case studies for flexible and rigid pavements in urban and rural regions within two different climatic zones are discussed. Cost responsibilities for pavement maintenance and rehabilitation are presented individually for six vehicle classes and on a cent-per-ESAL-mile basis. Although the values differ by pavement type, environmental region, and economic criterion used, in general they show that heavy combination trucks bear approximately 1000 times the cost responsibility of automobiles for pavement maintenance and rehabilitation. Differences between flexible and rigid pavements and between climatic zones are also highlighted.

The nationwide system of streets and highways, one of the most important public investments in the United States, is financed primarily by highway user charges. Of the $37.5 billion in receipts designated for highway purposes in 1979, about $22.8 billion, or 61 percent, was derived from imposts on highway users, primarily in the form of a full tax imposed at the federal, state, and (to a limited extent) county and municipal levels. Another $10 billion, or 27 percent, was received through other taxes and fees, mainly property assessments and general revenues earmarked for local roads at the county and municipal levels (1). Although there has been no opposition to the notion that users should pay for highway services, the amount that each class of user (or class of vehicles) should pay is open to controversy and involves a host of technical, economic, and political issues.

As a result, many studies under the generic title of highway cost allocation have been conducted by federal and state agencies. The first major federal cost-allocation study was mandated in 1956 by the Highway Revenues Act, which established the Highway Trust Fund. This study lasted until 1965, and its findings were updated twice, in 1969 and 1975. However, recognizing the unreliability of extrapolating earlier results and the potential need for new highway taxes, the Congressional Budget Office (CBO) in 1978 recommended a new highway cost-allocation study (2). In November 1978, Congress passed the Surface Transportation Assistance Act, which mandated a comprehensive cost-allocation study by the U.S. Department of Transportation (DOT) and a concurrent review of the existing and alternative tax structures. The cost-allocation studies conducted by states bear strong ties to the 1956 and 1978 federal studies, although some states have actively developed their own cost-allocation methods.

FOCUS OF OUR RESEARCH

The early federal and state studies were performed during a time of major highway construction; not unexpectedly, methods for allocating pavement maintenance costs were neglected (or were patterned after the method of construction cost allocation). By the time of the 1978 study, however, the highway system had aged, and both the CBO and the performing agency for DOT, the Federal Highway Administration (FHWA), recognized that allocation of maintenance and rehabilitation costs was an important issue.

Our research was undertaken as part of the 1978 study to investigate allocation of life-cycle highway pavement costs, which considered explicitly the maintenance and rehabilitation costs incurred as the result of wear and tear due to traffic and the environment. Thus, the costs of pavement construction and reconstruction are not considered in the results reported in this paper. Moreover, since our study has focused on the costs of structural pavement damage, other costs--such as those due to loss of skid resistance, to problems in materials characteristics (e.g., bleeding), to shoulder maintenance, or to opening of longitudinal construction joints (in flexible pavements)--have likewise not been included. As used in this paper, the term "pavement life-cycle costs" therefore refers to costs incurred through the life of the pavement for routine structural maintenance (patching, crack filling, mudjacking, joint sealing, etc.) and for overlays.

The prime objectives of this study were (a) to develop a sound framework for attributing pavement maintenance and rehabilitation costs to different vehicle classes based on the pavement deterioration attributable to each vehicle class and (b) to illustrate how this framework can be applied to develop highway user charge responsibilities. Other issues, such as the effects of using different cost-attribution methods on user charge responsibilities, the impact of environment and pavement type on maintenance and rehabilitation costs, and the implications of life-cycle cost analyses, were also studied.

Determining appropriate user charge responsibilities requires two analytical steps: (a) cost estimation and (b) cost allocation among vehicle classes. To estimate the pavement maintenance and rehabilitation costs arising from road deterioration, a computer simulation model was used to predict pavement performance and life-cycle costs. For cost allocation, theoretical concepts and practical approaches were reviewed to develop allocation methods that satisfied the objectives and constraints of the federal study.

Two broad classes of allocation objectives are generally recognized in the literature: equity and efficiency. Equitable charges attempt to reflect some notion of fairness. Although definitions of equity abound, in this paper we have followed the federal lead in focusing on the concept that users should pay for the highway costs they occasion, where costs here are defined as highway agency expenditures. By contrast, the concept of economic efficiency is well grounded in economic theory and entails computing short-run marginal costs attributable to each user or vehicle class. Costs here encompass not only agency expenditures for routine pavement maintenance and overlays, but also costs borne by the highway users for vehicle operation, travel time, and accidents. (Costs borne by nonusers, such as for air and noise pollution, were considered briefly in our study but are not discussed in this paper.) Costs computed under the efficiency objective are therefore sometimes referred to as total social costs, to differentiate them from agency expenditures.

The choice between equity and efficiency is a political decision, which then dictates appropriate analytical methods and procedures to be used in the allocation process. Accordingly, we have estimated user charge responsibilities for each vehicle class for both the equity and the efficiency criteria. Comparisons between the two results will be presented later in this paper.

The research conducted for DOT emphasizes the systematic development of a rational approach for highway cost estimation and allocation. The details of this methodology are presented elsewhere (3) and encompass the following issues:

1. A description of the process of determining highway user charges;
2. An examination of goals and constraints in user charge determination and associated issues (e.g., the definition of equity and compatibility between equity and efficiency);
3. An examination of goals and constraints in user charge determinations;
4. Estimation of maintenance and rehabilitation costs over the life of the pavement, which considers important technical and economic variables relating to pavement structural and material properties, environmental factors, maintenance policies and technologies, traffic characteristics, unit costs, and so forth; and
5. Allocation of costs under both equity and efficiency criteria.

This paper summarizes the results of this cost-allocation study. First we present below a brief description of the simulation model used to estimate pavement maintenance and rehabilitation costs. Then we develop an outline of the case studies investigated. Finally, we present some of the key results obtained.

OVERVIEW OF SIMULATION MODEL

Since the cost-allocation data were estimated by the EAROMAR-2 simulation model, it is desirable for the reader to have a general understanding of the nature and characteristics of this model. The following is a very abbreviated description; details of this model are provided elsewhere (4).

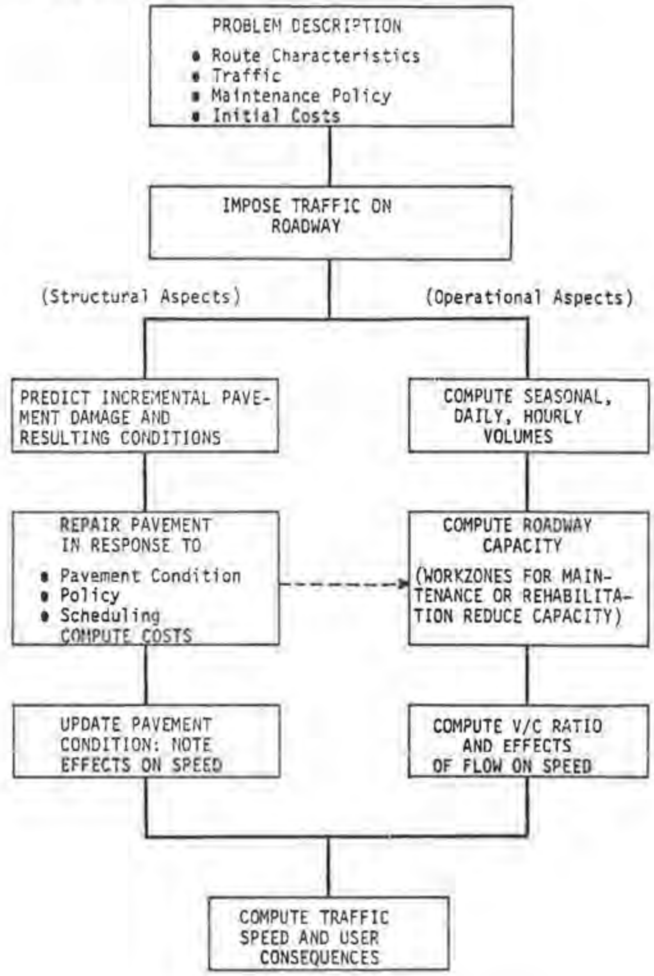
The economic analyses performed by EAROMAR-2 are based on simulations of highway performance and costs, which encompass both the structural (i.e., pavement related) and the operational (i.e., speed and flow related) aspects of road use, as shown in Figure 1. Costs predicted include highway agency expenditures for route or pavement reconstruction, pavement overlays, and pavement routine maintenance, and user costs of vehicle operation, travel time, and accidents, all discounted through an analysis period.

Costs are calculated through successive seasons within years; in each season the collective influences of pavement structural and materials properties; imposed traffic loadings; environmental factors; maintenance policies; local practices on work scheduling; and prevailing unit costs of maintenance labor, equipment, and materials on pavement damage and corresponding maintenance, rehabilitation, or reconstruction requirements are accounted for. The following sections describe briefly the operation of each model component in Figure 1. Additional technical information on each phase of the analysis may be obtained from the FHWA report (4).

Problem Definition

Before the EAROMAR-2 analysis can proceed, the problem itself must be defined to the system through sets of technical, economic, and administrative parameters. Problem definition is the task addressed

Figure 1. Concept of EAROMAR simulation.



at the top of Figure 1. These input data establish the characteristics of the route to be studied, the scope of the economic analysis, and the policy alternatives to be investigated.

Economic analyses of highway investment or maintenance policies result from interactions among several geometric, operational, administrative, and economic variables that affect a road during its analysis life. For brevity and clarity, in Figure 1 route characteristics, traffic, and maintenance policy have been emphasized as important components of problem description. A more complete list of factors actually incorporated within EAROMAR-2 would encompass traffic volume, composition, and growth; roadway capacity in relation to demand volume; quality and thickness of pavement initially constructed; environmental factors affecting pavement performance; construction projects to upgrade route geometry, capacity, or pavement or to overlay pavement; standards of pavement serviceability and maintenance to be performed; maintenance technology, work-zone configurations, and scheduling; unit costs (and projected inflation in costs) of maintenance labor, equipment, and materials; budget or resource constraints on maintenance work; vehicle operating costs and values of travel time perceived by the user (with projected changes through the analysis period); and discount rates and length of road life used in the economic analysis.

Analysis Through One Season

The simulation in Figure 1 begins with the assignment of traffic of appropriate volume and composition to each roadway. Roadway geometry, capacity, and current pavement condition derive from the description of the route (whether new or existing) at the beginning of the analysis period, any modifications to the roadway accomplished under construction or overlay projects, the loadings to which the roadway pavement has been subjected, and past maintenance performed. Traffic volume and composition are determined from the initial annual average daily traffic (AADT), growth patterns, and composition of the traffic stream specified by the user.

We now track the flow of the simulation for one roadway through a given season of a year within the analysis period. Conceptually the simulation is divided into two branches, that dealing with structural deterioration and repair of the pavement surface and that treating roadway operational characteristics.

Structural Deterioration and Repair

Pavement Damage

The assignment of traffic to each roadway imposes axle loads that, in conjunction with moisture and temperature, damage the pavement. To estimate the type and magnitude of damage that occurs each season, the EAROMAR-2 system incorporates a set of damage models, as indicated at the top of the left-hand branch in Figure 1.

Models to predict pavement damage are included for two purposes. First, highway maintenance is often a demand-responsive activity in that work is done after damage has appeared. Therefore, to be able to estimate future maintenance requirements accurately, one must be able to predict the type and amount of damage expected to occur and when it will occur. Second, the condition of the highway surface affects user response and may have some bearing on speed, vehicle operating costs, and accident frequencies.

The models included within EAROMAR-2 are based on empirical pavement research or on closed-form approximations to theoretical model predictions. Damage predictions by these models are sensitive to pavement layer thicknesses, seasonal variations in materials properties, applied traffic loadings, and pavement age. In several cases no models exist to predict damage modes of interest; for these, users may provide directly their own estimates of rates of deterioration.

Maintenance and Rehabilitation

Maintenance and rehabilitation are treated within EAROMAR-2 as demand-responsive actions. This means that maintenance requirements in a given season are not extrapolated from historical trends of past work performed but rather are based directly on the type and amount of pavement damage predicted. How much damage is to be repaired among the several maintenance and rehabilitation activities simulated is a management decision expressed through the maintenance and rehabilitation policies, or quality standards.

These demand-side considerations control the determination of seasonal work requirements within EAROMAR-2. However, the actual conduct of work is also governed by supply-side constraints on resource availability and scheduled time allotted to each activity. Maintenance costs depend to some extent on the time of day at which work is carried out. Application of maintenance quality standards to the total damage present in a particular season results in a total maintenance workload for each activity in that period. The maintenance workload is then used as the basis for estimating seasonal maintenance costs.

To cost maintenance requires knowing the production rate, unit resource requirements, and unit costs for labor, equipment, and materials for each activity. The production rate is in units of damage required per hour. Unit resource requirements are the number of workers and the quantity and type of equipment and materials to be used. Unit costs are the dollar-per-hour costs for labor and equipment and unit quantity costs for materials. To the direct costs will be added other costs associated with the activity, such as those for traffic management and inspection. These costs will be summed over all types of damage repaired to arrive at seasonal maintenance costs.

Resulting Pavement Condition

The benefits of pavement maintenance and rehabilitation are accounted for in two ways within the EAROMAR-2 simulation. First, there is an immediate improvement in surface condition due to the damage repaired; if the repairs are significant enough, the present serviceability index (PSI) may also be increased somewhat. (Overlays restore the surface to essentially new condition.) Second, by restoring at least some of the pavement structural capacity lost through use and aging, maintenance and rehabilitation affect the rate of damage accumulation in the future.

By superimposing the results of two calculations--the accumulation of damage simulated by the deterioration models and the repair of damage discussed above--the resulting pavement condition this season is obtained. This revised condition encompasses updated values of all damage components and a recomputed PSI. The updated pavement condition has implications for several remaining steps in the analysis. First, if the pavement surface has deteriorated sufficiently, it may limit the speed of the traffic flow; this possibility is indicated at the lower part of the left-hand branch in Figure 1. Second, pavement condition affects the rates of vehicle fuel, oil, and tire consumption and will thus influence vehicle operating costs. Third, the net cumulative damage predicted by the model becomes part of the roadway damage history and will be used as the starting point of pavement damage analysis in the following season.

Roadway Operations

Roadway operating characteristics describe the level of service afforded motorists in speed and smoothness of flow. These characteristics are quantified within EAROMAR-2 in terms of free-flow speed, speed-change cycles, and congestion or queuing. The procedures involved are shown in the right-hand branch in Figure 1.

Demand Flows

Travel demand is represented by the traffic stream assembled by using data specified by the user. Demand flows are computed in vehicles per lane per hour for each of the 24 h of a typical weekday and of a typical weekend day. Hourly demand may vary along the roadway length.

Roadway Capacity

The capacity of the roadway may also vary over its length with changes in the number of lanes, roadway geometry, side clearances, and so forth. Capacity is computed in both passenger-car equivalents per lane per hour and vehicles per lane per hour for each hour of typical weekdays and weekends, according to procedures recommended in the Highway Capacity Manual (5). The effects of the percentage of trucks and of the vertical grade (if any) are explicitly accounted for.

As indicated in Figure 1, roadway occupancy for maintenance or rehabilitation causes a temporary local decrease in capacity. The amount of disruption depends on when repair work is scheduled, the extent of the work zone, and the duration of work (a function of both the amount of pavement damage present and the maintenance policy specified). Scheduling and work-zone characteristics, as well as maintenance technology and production rates, are controlled by the user in his or her description of each maintenance activity.

Speed-Flow Relationship

EAROMAR-2 simulates traffic operations along the entire roadway length and simultaneously accounts for daily (weekday versus weekend) and hourly variations in demand flows and road occupancy determined by maintenance policies and scheduling requirements discussed above. This procedure is indicated at the bottom of the right-hand branch in Figure 1. Uncongested flows are estimated by using speed-flow relationships developed from the Highway Capacity Manual (5). Where hourly demand exceeds local capacity (whether due to normal rush-hour peaks or to occupancy for pavement repair), congested flows are simulated over both the roadway length and the time. A speed-change cycle is also introduced on entry of the flow into the congested zone.

User Consequences

The last block in Figure 1 represents the calculation of user consequences. In most cases the operational aspects (i.e., the speed-flow relationship on the right-hand branch in Figure 1) will dominate this calculation. In cases of a badly deteriorated pavement, roadway surface condition itself may limit the speed. In either situation, however, pavement condition will affect the rate of fuel, oil, and tire consumption by each vehicle.

Models are included to compute vehicle operating costs, travel time and costs, accident costs, and pollution levels as functions of speed, speed changes, congestion, the characteristics of the vehicular traffic, and the current condition of the pavement surface. These calculations are performed for each hour of each type of day and account for any interruptions due to maintenance or rehabilitation.

Variations in user costs among different components of the traffic stream are automatically taken into account. For example, costs attributable to fuel consumption and emissions will vary by vehicle type. Values of travel time, on the other hand, are a function of trip purpose. Data from which these distinctions can be made are provided in the descriptions of travel demand.

Annual and Total Summaries

At the completion of each season's simulation, the following costs are assembled for use in the economic analysis:

1. Initial investment costs (if any) provided by the user at the beginning of the analysis;
2. Roadway maintenance and rehabilitation costs to repair pavement damage; and
3. User costs associated with vehicle operation, travel time, and accidents.

Seasonal totals are summed for each year. If components of the cost stream are subject to differential inflation, appropriate adjustments to costs are made; the annual costs are discounted at specified rate(s) and the discounted totals accumulated. At the completion of the simulation, the discounted maintenance and user costs are displayed, together with initial construction costs, to yield a total cost stream.

DEVELOPMENT OF CASE STUDIES

To demonstrate the application of the EAROMAR-2 results to cost allocation, eight case studies were developed that considered combinations of two environmental regions, two pavement types, and two traffic levels. The environmental regions typified the Northeastern and the Southwestern United States; they represented cold-wet and hot-dry conditions, respectively. The two pavement types comprised flexible (asphalt-concrete) and rigid (portland cement concrete), in each case designed according to the AASHTO method (6). The traffic levels corresponded respectively to high and low volumes and were taken from FHWA projections for urban and rural Interstate systems, respectively. Designs typical of the Interstate highway system were chosen in constructing the case studies; however, the cost-allocation concepts developed under this research apply to other classes of roads as well.

The eight highway cases tested had identical geometric characteristics consistent with Interstate standards. Each road consisted of a four-lane level-tangent divided highway that had 12-ft lane widths and 10-ft shoulders. Since highways were divided with an assumed 50-50 directional traffic split, we needed to look at only two of the four lanes of each route considered in the analysis; we assumed that the remaining two lanes had identical conditions. Consequently, the results must be interpreted with care; costs per mile pertain to a two-lane mile (i.e., a roadway mile, if only one traffic direction is considered).

FHWA had identified 38 vehicle classes for consideration in the DOT study. In this particular research these classes have been consolidated within six classes according to registered weight. Again, the conceptual basis of the study was not affected; the redefinition was done simply to reduce the analysis effort.

Details on the several categories of information specified for the case studies (road engineering characteristics, traffic volume and composition, maintenance policy and technology, unit costs, and so forth) are explained elsewhere (3, Appendix A) and would be too lengthy to present here. However, there are some aspects of case study design that should be understood in assessing the results below:

1. The focus of this project was to demonstrate the applicability of simulation models such as EAROMAR-2 to the allocation of life-cycle pavement costs and not to estimate total user charge responsibilities for pavements. Thus, only routine structural maintenance and rehabilitation costs were considered; other pavement-related costs, such as those for initial construction, shoulder maintenance, skid resistance, and pavement reconstruction, were not included.
2. To avoid slanting the analyses toward a particular environmental region or pavement type, certain elements of the case studies were addressed as objectively as possible, e.g., by holding certain

Table 1. ESAL factors used in analysis.

Vehicle Class	Vehicle Type	Flexible Pavement		Rigid Pavement	
		Urban	Rural	Urban	Rural
Northeast Region					
1	Automobile	0.000 361 2	0.000 368 5	0.000 348 1	0.000 353 5
2	Light single-unit truck	0.090 41	0.082 50	0.074 97	0.071 19
3	Heavy single-unit truck	0.359 2	0.252 7	0.187 7	0.136 2
4	Combination <25 tons	0.276 6	0.285 0	0.154 4	0.152 4
5	Combination 25-35 tons	0.332 1	0.381 2	0.179 9	0.181 2
6	Combination >35 tons	0.458 4	0.446 0	0.172 2	0.153 8
Southwest Region					
1	Automobile	0.000 501 4	0.000 665 2	0.000 473 2	0.000 620 9
2	Light single-unit truck	0.066 72	0.078 29	0.056 37	0.066 59
3	Heavy single-unit truck	0.298 9	0.381 4	0.162 0	0.195 3
4	Combination <25 tons	0.495 6	0.751 4	0.172 4	0.192 4
5	Combination 25-35 tons	0.380 4	0.376 7	0.135 7	0.134 3
6	Combination >35 tons	0.549 0	0.556 5	0.270 5	0.255 5

parameters constant or by relying on data provided by FHWA as part of their own cost-allocation effort. These assumptions, however, themselves influenced comparisons between environmental regions and pavement types, and therefore should be taken into account:

a. Environmental parameters (regional factor, temperature, rainfall, and freezing index) and subgrade soil classifications represented very broad regional characteristics encompassing several states in the Northeast and Southwest, respectively. Therefore they may not coincide with the general characteristics of individual states, let alone those of specific areas within a state.

b. The AASHTO design procedures (6) were used to determine pavement thicknesses (in response to projected traffic) for both flexible and rigid pavements in each of the environmental regions. However, other than for variations in traffic, environmental parameters, and subgrade soil classification, no changes were made in the design procedures between the two regions. Specifically, the modulus of asphalt concrete was not adjusted between the two regions that had different temperature patterns. The relatively frequent overlays (and resulting higher costs) computed for flexible pavements in the Southwest are due in part to this fact.

c. Traffic streams simulated on the rigid pavements and the flexible pavements consisted of different numbers of vehicles:

Region	Flexible Pavement		Rigid Pavement	
	Urban	Rural	Urban	Rural
Northeast	29 054	9323	29 054	9323
Southwest	50 136	6392	50 136	8715

Also, the equivalent single axle-load (ESAL) factors of the respective vehicle classes differed among pavement type, region, and urban or rural designation, according to data provided by FHWA and summarized in Table 1. Thus, the costs among different pavements and regions were calculated by assuming different vehicle streams.

3. The costs of maintenance and rehabilitation computed in this study derive (as explained earlier) from predictions of pavement damage; the study results are therefore sensitive to the damage equations within EAROMAR-2. Although many of the equations incorporate environmental factors (e.g., temperature) or pavement characteristics that vary seasonally (e.g., layer moduli), most of the models simulate damage as occurring from a combination of environmental stresses and induced traffic loads. (The only "purely environmental" components of damage currently simulated within EAROMAR-2 are cold-weather cracking of asphalt pavements and spalling and blowups of portland-cement pavements.) Therefore, maintenance and rehabilitation costs are heavily dependent on traffic, measured in total number of vehicles or in cumulative ESALs.

RESULTS

Results were developed for the eight cases defined above. First, routine maintenance and rehabilitation costs (referred to below simply as maintenance costs) attributable to each vehicle class were simulated by using the EAROMAR-2 procedure. (Separate vehicle classes were in fact studied in our research. However, results by vehicle class agreed well with results expressed in terms of the number of 18-kip ESALs. The data reported below therefore may show either representative vehicle class or ESAL.) Then, costs were allocated by vehicle class (or ESAL) by using both the equity and the efficiency criteria. For brevity, only selected examples of the results are given below; the complete set of tables and figures is given elsewhere (3).

User Charge Responsibilities According to Equity

Pavement maintenance costs for both the base traffic and no traffic were determined so as to calculate the portion of maintenance costs that is attributable to traffic. The results indicate that the non-traffic-related pavement maintenance costs of flexible pavements are very small--less than 1 percent of the maintenance costs of the base traffic. The major cause of these purely environmentally induced maintenance activities is cold-weather lineal cracking. The non-traffic-related pavement maintenance costs for rigid pavements are higher; they range between 5 to 7 percent of the base maintenance and are primarily due to spalling of concrete and blowups between pavement slabs.

Table 2 determines the unit costs of the traffic-related pavement maintenance costs. The annual traffic-related maintenance costs are obtained by subtracting the annual non-traffic-related pavement maintenance costs from the annual base-traffic maintenance costs; they are then divided by the number of ESAL applications per year to arrive at the maintenance cost per ESAL mile.

Table 3 illustrates the computation of equitable pavement maintenance cost responsibilities for each vehicle class in terms of average cost per vehicle mile. In order to compute the cost responsibility of a vehicle class, the unit cost (from Table 2) is multiplied by the corresponding ESAL factor (from Table 1). Similar calculations were made for the

Table 2. Traffic-related life-cycle pavement maintenance cost for Interstate highways.

Roadway Type	Annual Cost ($/mile) Under Base Traffic	Under No Traffic	Traffic-Related	ESAL per Year	Unit Cost (¢/ESAL mile)
Northeast Region					
Urban flexible	6 754	29	6 716	669 904	1.0025
Urban rigid	2 886	147	2 739	316 506	0.8654
Rural flexible	5 174	46	5 128	281 732	1.8202
Rural rigid	2 666	151	2 515	120 140	2.0934
Southwest Region					
Urban flexible	11 044	21	11 022	252 932	4.3577
Urban rigid	2 376	146	2 230	117 183	1.9030
Rural flexible	7 024	15	7 009	144 084	4.8645
Rural rigid	2 247	141	2 106	75 000	2.8080

Table 3. Equitable life-cycle pavement maintenance cost for Interstate highways in Northeast.

Vehicle Class	Flexible Pavement Cents per ESAL Mile	ESAL Factor	Cents per Vehicle Mile	Rigid Pavement Cents per ESAL Mile	ESAL Factor	Cents per Vehicle Mile
Urban						
Automobile	1.0025	0.0004	0.0004	0.8654	0.0003	0.0003
Light single-unit truck	1.0025	0.0904	0.0906	0.8654	0.0750	0.0649
Heavy single-unit truck	1.0025	0.3592	0.3601	0.8654	0.1877	0.1624
Light combination	1.0025	0.2766	0.2773	0.8654	0.1544	0.1336
Medium combination	1.0025	0.3321	0.3329	0.8654	0.1799	0.1557
Heavy combination	1.0025	0.4584	0.4595	0.8654	0.1722	0.1490
Rural						
Automobile	1.8202	0.0004	0.0007	2.0934	0.0004	0.0008
Light single-unit truck	1.8202	0.0825	0.1502	2.0934	0.0712	0.1491
Heavy single-unit truck	1.8202	0.2527	0.4600	2.0934	0.1362	0.2851
Light combination	1.8202	0.2850	0.5188	2.0934	0.1524	0.3190
Medium combination	1.8202	0.3812	0.6939	2.0934	0.1812	0.3793
Heavy combination	1.8202	0.4460	0.8118	2.0934	0.1538	0.3199

Table 4. Equitable user charge responsibilities for life-cycle pavement maintenance on Interstate highways.

Vehicle Class	Flexible Pavement Urban	Rural	Rigid Pavement Urban	Rural
Northeast Region				
Automobile	0.0004	0.0007	0.0003	0.0008
Light single-unit truck	0.0906	0.1502	0.0649	0.1491
Heavy single-unit truck	0.3601	0.4600	0.1624	0.2851
Light combination	0.2773	0.5188	0.1366	0.3190
Medium combination	0.3329	0.6939	0.1557	0.3793
Heavy combination	0.4595	0.8118	0.1490	0.3199
Southwest Region				
Automobile	0.0022	0.0034	0.0010	0.0017
Light single-unit truck	0.2907	0.3809	0.1073	0.1870
Heavy single-unit truck	1.3205	1.8553	0.3083	0.5484
Light combination	2.1597	3.6552	0.3281	0.5403
Medium combination	1.6577	1.8325	0.2582	0.3771
Heavy combination	2.3924	2.7071	0.5148	0.7174

cases tested in the Southwest environmental zone.

The resulting equitable user charge responsibilities (in cents per vehicle mile) for life-cycle pavement maintenance cost on the Interstate highways are compared in Table 4. The equitable cost responsibilities for the flexible pavements, rural roadways, and the roadways in the Southwest are higher than those of the rigid pavements, urban roadways, and the roadways in the Northeast, respectively. Automobiles pay a very little share of the pavement maintenance cost; however, they and all other vehicles are responsible for other types of maintenance costs (such as those for maintaining traffic signals and signs), for pavement construction costs, and for common costs that have not been included in this analysis. Until all such cost responsibilities are computed, it is unclear which class of vehicle will benefit more under this equity-based scheme.

In general, the rigid pavements benefit from the longer interval simulated between overlays (effectively reducing the per-mile cost responsibility). This longer life depends on the respective pavement design procedures used. Furthermore, a fair comparison between flexible and rigid pavements must also include the pavement construction costs as well as other pavement maintenance and rehabilitation costs (e.g., for skid resistance), comparisons that were not included as part of this study. The relatively high flexible pavement costs observed in the Southwest are due in part to the effects of high temperature. (Simulation of a stiffer asphalt mix would reduce some of the damage predicted and maintenance costs observed.) Higher costs for the rigid pavements in the Southwest are also due to environmental effects, in particular the greater incidence of fatigue cracking induced by thermal stresses.

User Charge Responsibilities According to Efficiency

Efficient user charge responsibilities are determined according to the first-best short-run marginal cost pricing rule. Since the relevant cost for efficiency-based pricing is marginal total social cost, we need to consider not only pavement maintenance expenditures but also road user costs.

Marginal Life-Cycle Pavement Maintenance Cost

There are two basic steps in determining the marginal pavement maintenance cost. The first step is to determine the marginal pavement maintenance cost with respect to the ESAL level. The second step is to multiply this cost per ESAL by the ESAL factor of vehicle class i to obtain the marginal pavement maintenance cost responsibility of each class-i vehicle trip.

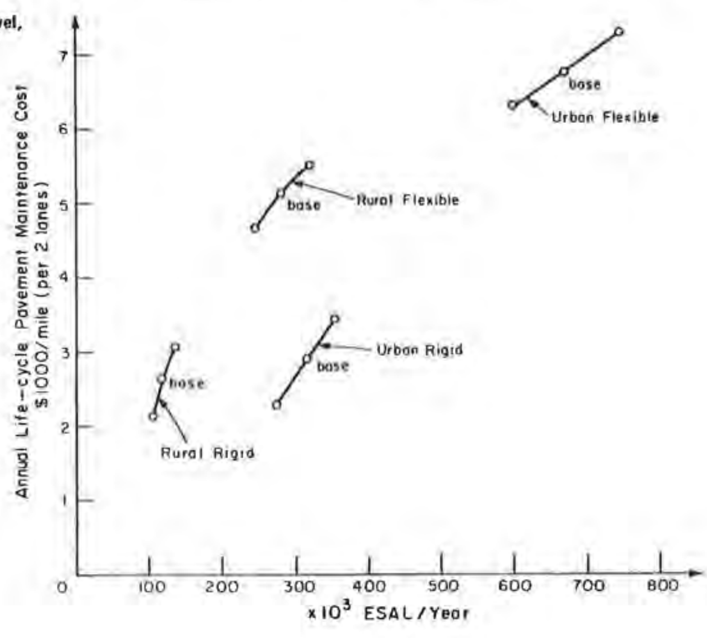
Table 5 summarizes the efficient user charge responsibilities (in cents per vehicle mile) for life-cycle pavement maintenance for Interstate highways. The efficient user charges for rigid pavements, rural roadways, and the roadways in the Southwest are higher than those on flexible pavements, urban roadways, and the roadways in the Northeast, respectively, for the same reasons as those discussed earlier for the equity-based results.

Rural roadways exhibit higher marginal costs than urban roadways because of long-run economies of scale with respect to ESAL, as shown in Figure 2 for the Northeast region. The results in Figure 2 actually capture two competing trends:

Table 5. Efficient user charge responsibilities for life-cycle pavement maintenance on Interstate highways.

	Flexible Pavement		Rigid Pavement	
Vehicle Class	Urban	Rural	Urban	Rural
Northeast Region				
Automobile	0.0002	0.0004	0.0003	0.0010
Light single-unit truck	0.0591	0.0953	0.0935	0.2080
Heavy single-unit truck	0.2350	0.2920	0.2341	0.3980
Light combination	0.1810	0.3294	0.1925	0.4453
Medium combination	0.2173	0.4400	0.2243	0.5294
Heavy combination	0.2999	0.5154	0.2147	0.4494
Southwest Region				
Automobile	0.0010	0.0019	0.0010	0.0016
Light single-unit truck	0.1287	0.2223	0.1169	0.1784
Heavy single-unit truck	0.5767	1.083	0.3360	0.5231
Light combination	0.9562	2.133	0.3576	0.5154
Medium combination	0.7339	1.069	0.2814	0.3597
Heavy combination	1.0590	1.580	0.5610	0.6844

Figure 2. Life-cycle pavement maintenance cost versus ESAL level, Northeast region.



1. Increasing numbers of ESALs per year cause increased damage to a given pavement and correspondingly higher maintenance costs. This short-run relationship is indicated by the solid-line segments for each pavement classification in Figure 2.

2. Incremental increases in pavement thickness substantially increase the design capacity of pavement (in terms of cumulative ESALs). In other words, adding 1 in to a 4-in pavement increases its design capacity by much more than 25 percent. The fact that this trend dominates the first trend can be inferred by the long-run comparisons between urban and rural flexible pavements in Figure 2. Each urban pavement carries more traffic than its rural counterpart, but it is also designed to higher standards.

The net result is the concave relationship between life-cycle pavement maintenance costs and annual ESAL applications in Figure 2, which implies long-run economies of scale. Whether these results are general and would be achieved for different maintenance policies or for different pavement damage equations is difficult to say; the issue requires more research. Within our own study, however, the same results were in fact also observed in the results for the Southwest region.

Efficient User Charge Responsibilities for User Costs

Highway users experience average user costs. In the computation of efficient user charge responsibilities, these out-of-pocket costs must be subtracted from the marginal user costs. The major components of user costs are travel-time cost and vehicle operating cost.

Our analyses showed that the differences between marginal and average travel-time costs were small because the simulated 55-mph speed limit caps the traffic speeds. Even when the volume/capacity ratio is small, the traffic stream could not (theoretically) go beyond the speed limit. Therefore, changes in traffic volume have little effect on travel time and travel-time costs. Since trucks have greater impact on the travel time of a traffic stream than automobiles, their congestion tolls on travel time are higher.

The two major types of vehicle operating costs that are affected by other vehicle trips are fuel

Table 6. Efficient user charge responsibilities for Interstate highways in Northeast.

Roadway Type	Vehicle Class	Component			
		Pavement Maintenance	Travel Time	Vehicle Operating	Total[a]
Urban flexible	Automobile	0.0002	0.3782	-0.2718	0.1066
	Medium combination	0.2173	0.6560	0.3834	1.2567
	Heavy combination	0.2999	0.9401	0.1212	1.3612
Urban rigid	Automobile	0.0003	0.6564	-0.2412	0.4155
	Medium combination	0.2243	2.9070	2.6536	5.7849
	Heavy combination	0.2147	2.9070	2.3218	5.4435
Rural flexible	Automobile	0.0004	0.1531	0.0112	0.1647
	Medium combination	0.4406	0.6020	1.1398	2.1824
	Heavy combination	0.5154	0.5959	0.8701	1.9814
Rural rigid	Automobile	0.0010	0.1429	-0.0399	0.1040
	Medium combination	0.5294	0.8582	1.9074	3.2950
	Heavy combination	0.4494	0.7410	1.9682	3.1586

[a]Total efficient user charge responsibilities here do not include pollution costs.

Table 7. Comparison of equitable and efficient user charge responsibilities in life-cycle pavement maintenance.

Vehicle Class	Flexible Pavement				Rigid Pavement			
	Urban		Rural		Urban		Rural	
	Equitable	Efficient	Equitable	Efficient	Equitable	Efficient	Equitable	Efficient
Northeast Region								
Automobile	0.0004	0.0002	0.0007	0.0004	0.0003	0.0003	0.0008	0.0010
Light single-unit truck	0.0906	0.0591	0.1502	0.0953	0.0649	0.0935	0.1491	0.2080
Heavy single-unit truck	0.3601	0.2350	0.4600	0.2920	0.1624	0.2431	0.2851	0.3980
Light combination	0.2773	0.1810	0.5188	0.3294	0.1336	0.1925	0.3190	0.4453
Medium combination	0.3329	0.2173	0.6939	0.4400	0.1557	0.2243	0.3793	0.5294
Heavy combination	0.4595	0.2999	0.8118	0.5154	0.1490	0.2147	0.3199	0.4494
Southwest Region								
Automobile	0.0022	0.0010	0.0034	0.0019	0.0010	0.0010	0.0017	0.0016
Light single-unit truck	0.2907	0.1287	0.3809	0.2223	0.1073	0.1169	0.1870	0.1784
Heavy single-unit truck	1.3025	0.5767	1.8553	1.0830	0.3083	0.3360	0.5484	0.5231
Light combination	2.1597	0.9562	3.6552	2.133	0.3281	0.3576	0.5403	0.5154
Medium combination	1.6577	0.7339	1.8325	1.069	0.2582	0.2814	0.3771	0.3597
Heavy combination	2.3924	1.0590	2.7071	1.580	0.5148	0.5610	0.7174	0.6844

and tire cost. For a given roadway, the fuel cost is usually affected positively by the traffic speed, which is in turn influenced negatively by traffic volume and affected secondarily and positively by pavement condition. The tire cost is affected primarily and negatively by the pavement condition and secondarily and positively by traffic speed. In general, fuel cost and tire cost tend to act in opposite directions when traffic volume changes. With this information in mind, having negative efficient cost responsibilities for operating costs is not surprising. Since having more automobiles in the traffic stream has almost no effect on pavement condition but can reduce the traffic speed and fuel cost, it is reasonable that the efficient cost responsibilities for vehicle operation of the automobiles on the urban roadways are negative and close to zero on the rural roadways. The efficient cost responsibilities of trucks are higher than those of the automobiles because their influence on the tire costs of other vehicles is due to their large impacts on the pavement condition.

Table 6 is a summary of all the components of efficient user charge responsibility (in cents per vehicle mile) discussed previously. The efficient cost responsibility of each vehicle trip should be the sum of all the listed components. The ranking of the roadways in terms of highest efficient cost in descending order is as follows: urban rigid, rural rigid, rural flexible, and urban flexible. As indicated by the ranking, it is not necessarily true that the efficient cost responsibilities are higher on urban Interstate highways than on rural Interstate highways. When the congestion toll on travel time is small, other efficient cost components become important. In fact, the efficient cost responsibilities on rigid pavements are higher than those on flexible pavements because their vehicle operating-cost components are larger. Because the urban rigid roadway also has a large component of efficient cost responsibility for travel-time cost, it ranks the highest in efficient cost responsibility. Marginal pavement maintenance cost is not a large component in efficient cost responsibility; it is less than 25 percent of the total for the combination trucks and even less for automobiles.

Comparison of Equitable and Efficient User Charge Responsibilities

Table 7 summarizes the results of the equitable and efficient user charge responsibilities (in cents per vehicle mile) for life-cycle pavement maintenance costs. The efficient charge corresponds to short-run marginal costs, whereas the equitable charge corresponds to short-run average variable costs. The non-traffic-related (fixed) costs have been removed from the equitable charge. On the whole, the results show that the equitable and efficient user charges are significantly different (except for the Southwest rigid roadways). The equitable charges are greater than the efficient charges on all of the flexible pavements, which implies that collecting charges based on efficiency cannot cover the pavement maintenance budget of flexible pavements.

CONCLUSIONS

The objective of this study has been to demonstrate how user charge responsibilities for life-cycle pavement maintenance costs can be developed by using detailed simulations of roadway performance and costs. Two different economic objectives were investigated: one based on equity (to allocate highway maintenance expenditures) and the second based on efficiency (considering total social costs). The detailed procedures for estimating life-cycle pavement cost data and processing these data into relevant cost-allocation information have been developed elsewhere (3).

Several assumptions have been made in this study that affect the results and their interpretation. For example, the case studies are predicated on the design standards of Interstate highways, and the findings may not apply to other types of roadways. (For instance, non-traffic-related damage may be higher on other classes of roads.) Also, the technical and economic findings, particularly comparisons between cases (flexible versus rigid pavement, urban versus rural highways), are strongly influenced by the pavement models included in the EAROMAR-2 simulation model as described by Markow and Brademeyer (4). Furthermore, pavements were simulated with traffic streams of different volumes and compositions. Finally, costs discussed in this paper encompass routine structural maintenance and overlays but no other pavement-related costs or shoulder-related costs associated with construction or maintenance.

With these caveats in mind, the following are some general conclusions of our study:

1. The life-cycle costs attributable to heavy trucks are, in order of magnitude, about 1000 times those estimated for automobiles. This finding is due almost entirely to the particular assumption of vehicle ESAL factors used in this study as shown in Table 1. It is apparent that the factors, computed from data provided by FHWA, reflect some average truck weight rather than maximum gross weight. Nevertheless, there was some concern raised during the study that the ESAL factors in Table 1 might not be accurate.

2. For both flexible and rigid pavements, purely environmental pavement damage (i.e., damage that has no dependence whatsoever on traffic loads) amounts to less than 10 percent of total life-cycle costs. This is to be expected from the types of pavement damage models included within EAROMAR-2; although these models do include the effects of temperature, rainfall, and freezing index, the environmental factors are applied in conjunction with traffic loadings (whether ESALs or other vehicle parameters) in most of the damage equations (4).

3. Generally speaking, the life-cycle costs of rigid pavement are less than those of flexible pavement, due to the longer intervals between overlays simulated for portland cement concrete. Bear in mind, however, that the life-cycle costs computed in this paper represent only a portion of total pavement costs. Construction costs and other maintenance costs (e.g., shoulder maintenance, skid-resistance maintenance, correction of construction or materials deficiencies) would have to be included to make a fair cost comparison between pavement types.

4. The study has shown the feasibility of applying the life-cycle cost-allocation approach to different environmental zones. However, a direct comparison between results for the Northeast and the Southwest obtained in this study is complicated by the different traffic characteristics assigned in each region (Table 1) and the fact that asphalt layer moduli were not adjusted in the pavement design for the higher temperatures in the Southwest. Additional analyses would clarify the role of regional environment in affecting life-cycle costs.

Recently, we have been attempting to compare our maintenance costs results with those produced under the federal Highway Cost-Allocation Study (HCAS) (7). In general, the results obtained in our study, under both the equity and the efficiency criteria, appear to impose less cost responsibility on vehicles than do the federal computations. A direct comparison is somewhat difficult because the two studies report their results in different ways. However, the following components are pertinent:

1. Our study has computed user pavement responsibilities based on an estimation of life-cycle costs and a distribution of uniform charges (over time) to users throughout an analysis period. The federal study has proceeded from a somewhat different premise--to allocate current estimated program expenditures based on pavement damage accumulated in the past, as well as additional damage predicted in the future. The two philosophies may in fact yield markedly different results. In addition, our analyses indicate that the pay-as-you-go principle currently underlying federal highway funding may at least have to be reviewed in financing maintenance and rehabilitation.

2. Estimation of pavement rehabilitation costs in our study and in the federal HCAS relied on different models of pavement damage and resulting costs. Therefore, some differences in the absolute values of the predicted costs, in allocation among vehicle classes, and in the ratio of traffic-related to non-traffic-related costs should be expected.

3. User charge responsibilities by vehicle class reported in the federal HCAS (7) apply generally to the highway system as a whole. Results reported in this paper apply only to Interstate highways in two regions of the country.

4. The federal study considered only pavement rehabilitation and excluded routine maintenance. In this study we have considered routine structural maintenance and rehabilitation but have excluded certain other types of pavement maintenance (identified earlier in the paper).

5. In demonstrating use of the simulation model and subsequent calculations, we have focused on those variable costs (under the equity objective) or marginal costs (under the efficiency objective) that are attributable to traffic. Common costs (for equity) or residual costs (for efficiency) are not included in Tables 1-7. Since the federal HCAS has implicitly considered all user charge responsibilities, the results given earlier in this paper may show a lesser burden for all vehicle classes than do those of the federal HCAS.

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The contents of this report reflect our views and we are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of DOT. This document does not constitute a specification or a standard.

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Methodology for Evaluating Increase in Pavement Maintenance Costs That Result From Increased Truck Weights on Statewide Basis

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When this study was made, Indiana's weight limits for trucks were 18 000 lb on a single axle, 32 000 lb on a tandem axle, and 73 280 lb gross vehicle weight (GVW). The federal limits for the Interstate system and other primary roads were 20 000 lb on a single axle, 34 000 lb on a tandem axle, and 80 000 lb GVW. The objective of this study was to evaluate what the effects would be on pavement maintenance costs if Indiana's weight limits were increased to those of the federal limits. The methodology that was developed to evaluate the increase in load limits from 73 280 to 80 000 GVW is described. The road-life records of the Indiana Department of Highways were searched and pavement sections were evaluated by using these data coupled with truck weight information from the weight stations and soil and performance data available from previous studies. A total of 301 pavement sections were selected for evaluation. The types of pavements evaluated included continuously reinforced concrete, jointed reinforced concrete, asphalt, and concrete pavements overlaid with asphalt. The pavement sections were evaluated according to functional classification. The pavements were further divided on a regional basis so that climatic effects would be evaluated as well. Cost estimates were presented in dollars per lane mile per year and dollars per year for Interstates, primary roads (U.S. and state routes carrying more than 4000 vehicles/day), and secondary roads (U.S. and state routes carrying less than 4000 vehicles/day).

The Federal-Aid Highway Act of 1956 established the maximum weight limits for the Interstate system, which at that time were 18 000 lb on a single axle, 32 000 lb on a tandem axle, and 73 280 lb gross vehicle weight (GVW) (1). Since some states already permitted loads in excess of those specified by the Act, a grandfather clause was included to protect them from this Act (2).

After the 1973 energy crisis, the Federal-Aid Highway Act of 1974 raised the federal weight limits to 20 000 lb on single axles, 34 000 lb on tandem axles, and 80 000 lb GVW. At the time of this study, in 1978, nine states in addition to Indiana still maintained the 1956 weight limits. These states, known as "barrier states," lie in the midwestern part of the United States.

This paper presents the methodology used in this study to estimate the effect of increased truck weights on the service life of pavements, specifically on pavement maintenance costs.

The study was limited to evaluation of added load-related costs on the state system of Indiana highways, including Interstates and U.S. and state routes. This report deals with maintenance costs alone and does not consider changes in economic benefits that might result if weight laws were changed.

GENERAL BACKGROUND

Although pavement maintenance may be required for many reasons, including material breakdown and climatic effects, the number of heavy-load applications in terms of 18 000-lb equivalent single axle loads (ESALs) is a primary factor that causes pavement deterioration for a given set of conditions. Figure 1 shows the conceptual relationship between present serviceability index (PSI) and pavement life for a typical road that is exposed to an increase in load limits. It is to be noted that a change in load has an effect on pavement serviceability. If loads heavier than originally anticipated in the design are applied, the pavement will deteriorate more rapidly with two net effects. First, routine maintenance costs will increase and, second, the life of the pavement may decrease. On the other hand, if the pavement is designed for the newer and heavier loads, the change in serviceability will be essentially the same as that of the original pavement.

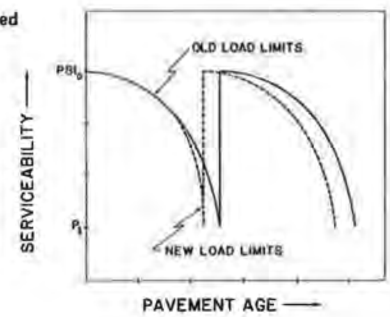
METHODOLOGY DESCRIPTION

The methodology adopted in this study to evaluate the effect of increased truck weights on pavement maintenance costs is shown in Figure 2 and is summarized as follows (3,4):

1. Collect data on pavement characteristics, traffic, soil type, climate, and unit costs;
2. Determine the total 18 000-lb ESALs under the existing and proposed load limits;
3. Predict the expected life cycle of all pavement sections (this includes predicting the time at which resurfacing is required as well as the thickness of overlay required);
4. Estimate future routine and major maintenance needs for all pavement sections;
5. Estimate total increase in maintenance costs for each year of the analysis period based on the difference of old and new load limits; and
6. Present the results in terms of equivalent uniform annual cost (EUAC).

The NULOAD computer program was used for determining the effects of increased truck weights on pavement performance and relating them to maintenance and rehabilitation costs (5,6).

Figure 1. Effect of increased load limits.



DESCRIPTION OF DATA USED

The information required to analyze the effects of increased truck weights on pavement maintenance costs can be classified into the following areas:

1. Road-life data,
2. Highway classification,
3. Pavement type,
4. Soil type,
5. Truck-weight data (traffic data),
6. Climate data, and
7. Routine and major maintenance cost data.

Road-Life Data

The road-life records of the Indiana Department of Highways (IDOH) consist of two standard forms that provide information in the following broad categories (7):

1. Design and construction features,
2. Bridges,
3. Construction costs,
4. Location,
5. General description of improvement, and
6. Retirements of improvement.

The above information is available for each route of the state highway system. The following information was obtained from the road-life records for this study:

1. Pavement type,
2. Pavement thickness,
3. Pavement age,
4. Layer components,
5. Construction costs, and
6. Last time of major improvement.

The computer program for this study uses the

Figure 2. Methodology to determine effect of new legal load limits.

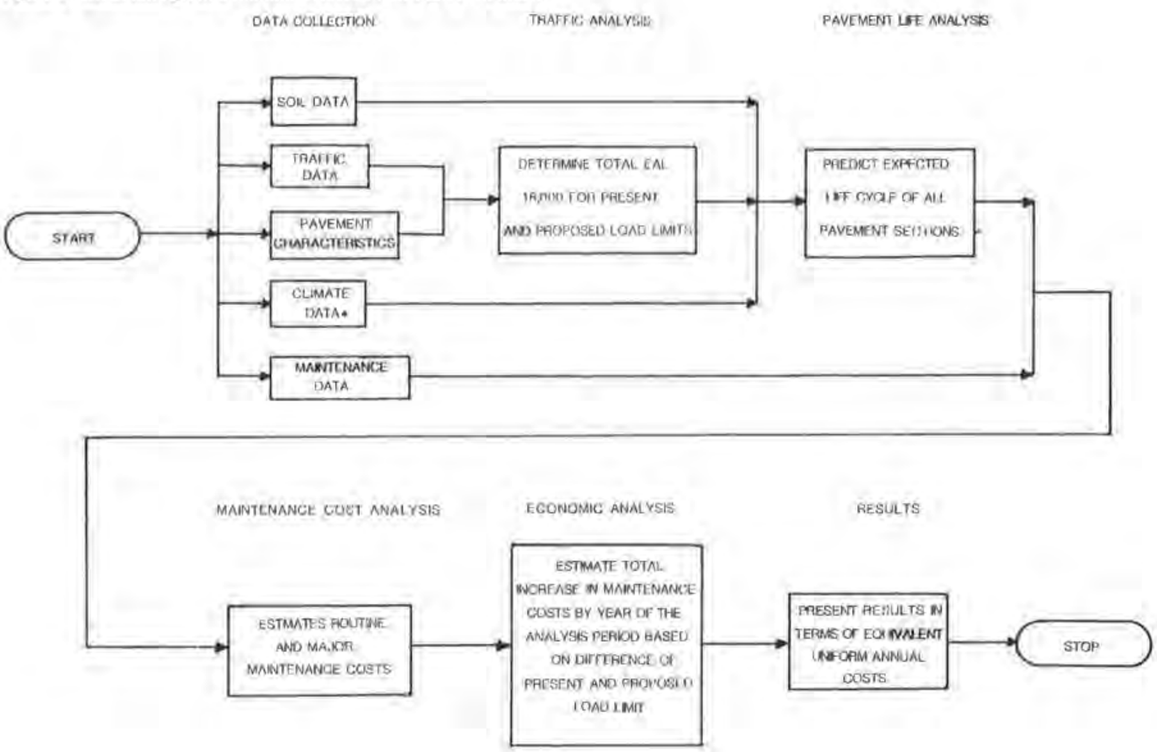


Table 1. Pavement design information.

Design Parameter	Value Adopted
Flexible Pavement	
Structural coefficient[a]	
a_1	0.44
a_2	0.14
a_3	0.11 (north and central Indiana) 0.14 (southern Indiana)
Initial PSI	4.2 (Interstate, primary, and secondary)
Terminal PSI	2.5 (Interstate and primary) 2.0 (secondary)
Analysis period	20
Regional factor	1.0 (southern Indiana) 1.1 (central Indiana) 1.5 (northern Indiana)
Soil-support value	See Table 2
Layer thickness	Road-life records
Rigid Pavement	
Modulus of rupture at 28 days (third-point loading)	700 psi
Working stress in concrete	525 psi
Modulus of elasticity	4 000 000 psi
Modulus of subgrade reaction	Correlation with CBR (prior to 1943) (see Table 2) 300 pci (after 1943)
Concrete thickness	Road-life records

[a] $SN = a_1D_1 + a_2D_2 + a_3D_3$.

Table 2. Soil-support values and modulus of subgrade reaction for major soil units of Indiana.

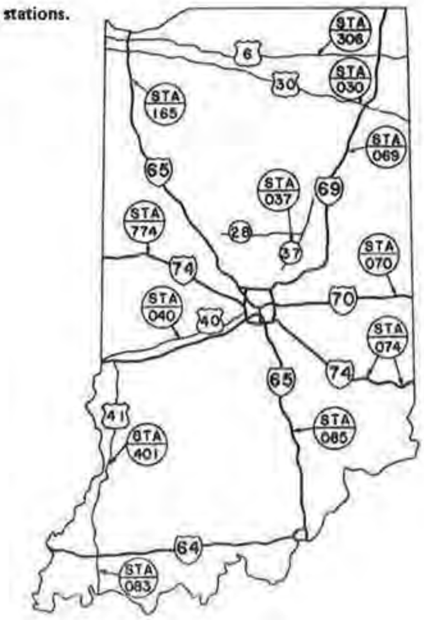
Major Soil Unit	Soil-Support Value (S)	Modulus of Subgrade Reaction (K)
Water transported		
Porous substrata (sands and gravel)	6.8	350
Sands (except Kankakee sands)	6.2	250
Kankakee sands	5.6	220
Lake beds	4.0	150
Ice transported		
Young drift till plains (silty clays), moraines	4.9	180
Areas of sand, gravel, and eskers	6.3	260
Old drift silts and silty clays	5.0	180
Wind transported		
Sand: some water-deposited sand areas include windblown sands	6.0	240
Loess—silt	5.3	200
Residual		
Limestone, interbedded limestone and shale, limestone, sandstone, and shale	4.9	180
Sandstone and some shale, interbedded shale and sandstone	5.1	190

structural design equations that were developed at the road test of the American Association of State Highway Officials (AASHO). Table 1 shows the values used in this study for both flexible and rigid pavements.

Highway Classification Used

Three road categories were considered in this study--Interstate, primary, and secondary. The distinc- tion between primary and secondary roads was based primarily on average daily traffic (ADT). Primary roads were U.S. and state routes with ADT > 4000 vehicles/day. Secondary roads were U.S. and state routes with ADT < 4000 vehicles/day. The Indiana traffic-flow map was used to determine the ADT of each of the pavement sections included in the sample (8).

Figure 3. Weigh stations.



Pavement Types Evaluated

For the purpose of this study the pavements encountered on the state highway system were classified into four major design categories as follows:

1. Flexible,
2. Jointed reinforced-concrete pavements (JRCP),
3. Continuously reinforced concrete pavements (CRCP), and
4. Overlay (asphalt over concrete).

Flexible pavements included an asphalt surface on a nonstabilized base and subbase on the natural subgrade and full-depth asphalt pavements.

JRCP are concrete pavements without an overlay and with joints (typically spaced at 40-ft intervals). In some cases plain pavements were placed in this category, but these were minimal since the older plain pavements have been overlaid.

CRCP are pavements without joints and that contain continuous steel.

Overlay pavements are concrete pavements with an appreciable amount of asphaltic concrete.

The actual classification of each pavement section was made after a search of the road-life records in the Planning Division of IDOH.

Soil Types Evaluated

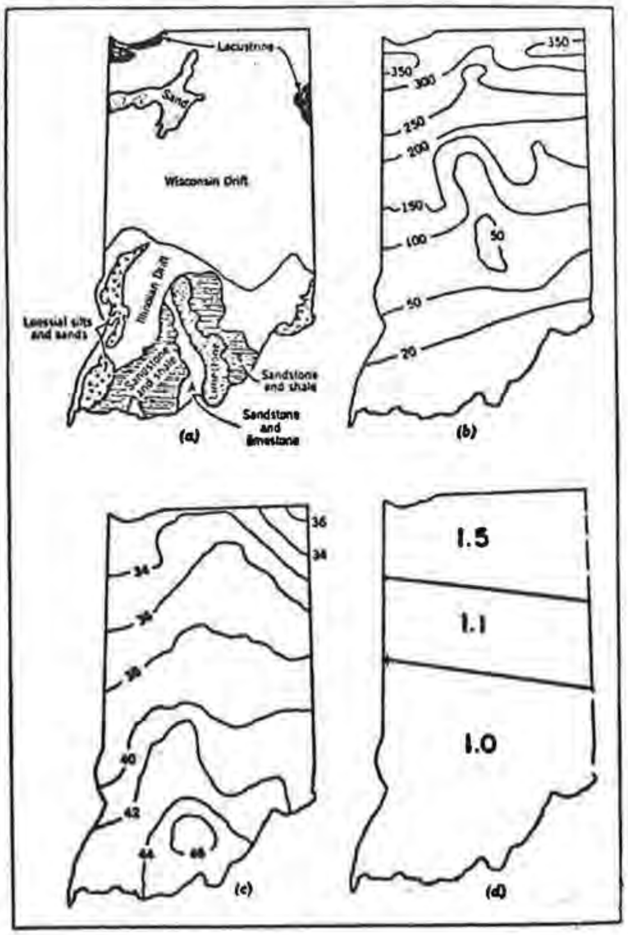
For the purpose of this study, the soils encountered in Indiana within the state highway system were classified into 11 design units as shown in Table 2. The classification of these soils was extracted from the engineering soil parent material map of Indiana (9).

The AASHTO design method requires the soil-support value as the measure of subgrade strength under flexible pavements and the modulus of subgrade reaction under rigid pavements. These design values are also tabulated in Table 2. The modulus of subgrade reaction was obtained from correlations with the soil-support value and the California bearing ratio (CBR) (10).

Traffic Data

Traffic data were obtained from the weigh stations opened in Indiana during the 1977 truck weight study (see Figure 3). These data were used along with the

Figure 4. Distribution of soils, rock, and climate in Indiana: (a) soils and rock, (b) mean freezing index (degree-days), (c) mean rainfall (inches/year), and (d) AASHTO regional zones.



AASHTO equivalency factors to calculate the 18 000-lb ESALs necessary for the analysis.

Since these traffic data correspond mainly to the Interstate system and some U.S. routes, a correction factor was applied to the original traffic data in order to provide a traffic distribution to the primary and secondary roads included in this study. These correction factors were obtained from the federal National Highway Inventory and Performance Study (NHIPS) report (11). A truck factor of 6 percent was used for the primary system and 4 percent for the secondary system.

Geographical Area

In this study, geographical area was considered to take into account the different climatic conditions from the ones encountered at the AASHO Road Test.

The following steps were undertaken to analyze the effect of climate on load-related costs:

1. The pavements in the state were stratified on a regional basis from north to south.
2. A correction factor was assigned to each of the regions in order to take into account climatic variations. These correction factors were developed in satellite research studies across the United States for the AASHO Road Test. The values used in this study were 1.5 for northern Indiana, 1.1 for central Indiana, and 1.0 for southern Indiana.

The final division of the state into three geographical regions was possible due to the unique relationships among soil type, freezing index, and rainfall as shown in Figure 4, which shows (a) a generalized distribution of the soils and rocks in the state, (b) freezing index, and (c) average rainfall contour lines for the state. It can be readily noted that soils as well as rainfall and freezing index distribute in a north-to-south direction.

The southern boundary of the northern region extends on a line from just north of Kentland in Newton County through Monticello in White County north of Marion and Grant County and north of Portland in Jay County. The southern boundary of the central region extends from a line just south of Newport in Vermillion County through a point north of Franklin in Johnson County and from there north of Lawrenceburg in Dearborn County.

Truck Types Evaluated

Six different types of trucks were evaluated in this study. These are shown in Figure 5 along with the old and new load limits of each truck.

The equivalency factors developed at the AASHO Road Test were used to convert the axle-load distributions of these trucks into 18 000-lb ESALs. These equivalency factors have been tabulated in many textbooks as a function of pavement thickness, magnitude of axle load, and terminal serviceability of the facility (12). Typical ESALs for the trucks considered in this study are shown in Figure 5 for a 10-in concrete pavement and a terminal serviceability of 2.5 for both present and proposed load limits.

SELECTION OF PAVEMENT SECTIONS

Two statistical techniques were used in this study for the selection of specific pavement sections. These were random and stratified sampling.

Random Sampling

This technique consisted of constructing an x-y coordinate chart that assigned a unique location to each area in Indiana. Numbers were then generated by using a standard table of random numbers. Two numbers were generated at the same time, which gave a specific location in the state. If there was a section of road within a 2-mile radius of that point, it was taken as one section of the sample. However, if there was no section, that location was dropped and another pair of numbers were generated.

Some 300 pavement sections were selected for evaluation by using the sampling technique discussed above. For each pavement section all the information described in previous paragraphs was recorded. Each section of road was a construction contract section that averaged 5 miles in length.

Strata Analysis

Strata analysis consisted of dividing the states into regions or zones, depending on the number of factors considered to be significant throughout the evaluation process. The procedure is commonly used when it is desirable to make certain that there is an adequate number of sections of each of the influencing factors under study; in addition, it helps in minimizing the variance within each influencing factor.

In this study the states were divided according to geographical area, pavement type, and functional classification. Soil type and traffic data were

Figure 5. Characteristics of trucks evaluated in this study.

	EAL Per Truck		Practical Maximum Gross Weight, lbs.	
	Old Load Limits	New Load Limits	Old	New
 2D	1.08	1.76	27,280	32,000
 3A	1.58	2.13	41,280	46,000
 2-S1	2.08	3.34	45,280	52,000
 2-S2	2.58	3.71	59,280	66,000
 3-S1	2.58	3.7	59,280	66,000
 3-S2	3.08	4.08	73,280	80,000

Table 3. Number of specific pavement sections included in study.

	Northern Area			Central Area			Southern Area		
		U.S. and State Roads			U.S. and State Roads			U.S. and State Roads	
Type of Pavement	Interstate	ADT >4000	ADT <4000	Interstate	ADT >4000	ADT <4000	Interstate	ADT > 4000	ADT <4000
CRCP	1	2	-	10	-	-	2	4	-
JRCP	17	1	1	15	3	3	4	2	2
Overlay concrete	4	24	15	3	17	14	7	14	16
Flexible	-	4	21	-	3	26	2	6	59

included but in a qualitative manner in the geographical classification. This technique proved to be efficient since it helped in recognizing the regions (strata) where there were not enough Interstate sections.

In summary, of the original 300 pavement sections, 256 were used, since the data of the remaining 44 sections were not available on the road-life records of IDOH. An additional 45 Interstate sections were selected for evaluation, since it was felt that any increase in load limits would be reflected more on the Interstate system. These highways now have the highest number of ESAL repetitions in the state (see Table 3).

TRUCK WEIGHT DISTRIBUTION ANALYSIS

Axle-Load Distribution

The axle-load distribution has been used for many years in the analysis of truck weight data, specifically to determine the 18 000-lb ESAL per truck. In addition, it provides useful information relative to the number of axles weighed in excess of the legal weights. The tables contain the necessary information to analyze the axle-load distribution of each vehicle class being considered in this study. Figure 6 shows the cumulative axle-load distribution of the 3-S2 truck observed during the 1977 truck weight study for both single and tandem axles. It is to be noted first that about 7 percent of the tandem axles weighed were in excess of the current load limits. Second, about 93 percent of the single axles weighed less than 12 000 lb.

The primary reason for using this statistical tool is the great variety of vehicles weighed in any one axle configuration type at any station and on any road system. With this method each type of truck can be analyzed separately according to the magnitude of load being carried. The steepness of the curves is in most cases the characteristic of interest.

GVW Distribution

Figure 7 shows the cumulative GVW distribution for the three trucks that most commonly traveled on Indiana highways at the time of this investigation. These were the 2-S1, 2-S2, and 3-S2 trucks. It can be readily noted that about 11 percent of the 3-S2 trucks weighed were in excess of the existing load limits of 73 280 lb. On the other hand, only about 1 percent of the 2-S1 and 2-S2 trucks were in excess of the AASHTO load limits of 45 280 and 59 280 lb.

Shifting Procedure for New Load Limits

The new load limits were analyzed by using the shifting procedure reported by Whiteside and others (13). Essentially, the axle-load distributions of any truck as well as the GVW distribution under the current load limits are basically shifted to the right in order to evaluate the effect of legal load limits on future truck weight distributions. The new axle-load and GVW distributions were determined by using the ratio of the practical maximum gross weight of each vehicle class. Practical maximum gross weight is defined here as the sum of the individual axle legal weights. The front or steering-axle weight was set at a reasonable amount consistent with that class of vehicle and what past roadside weighing has shown to be normal.

Although this method is statistically feasible, the truth is that it is very doubtful that an increase in the legal load limits on Indiana highways would accelerate an immediate shift to higher loads.

Figure 6. Cumulative axle-load distribution of 3-S2 truck under old load limits (rural Interstates).

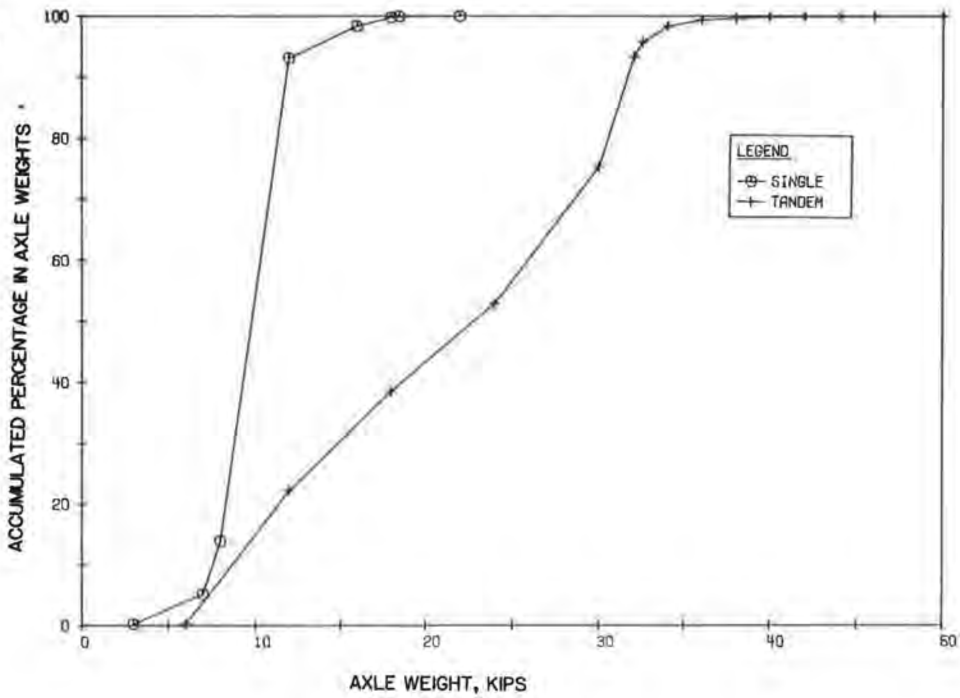
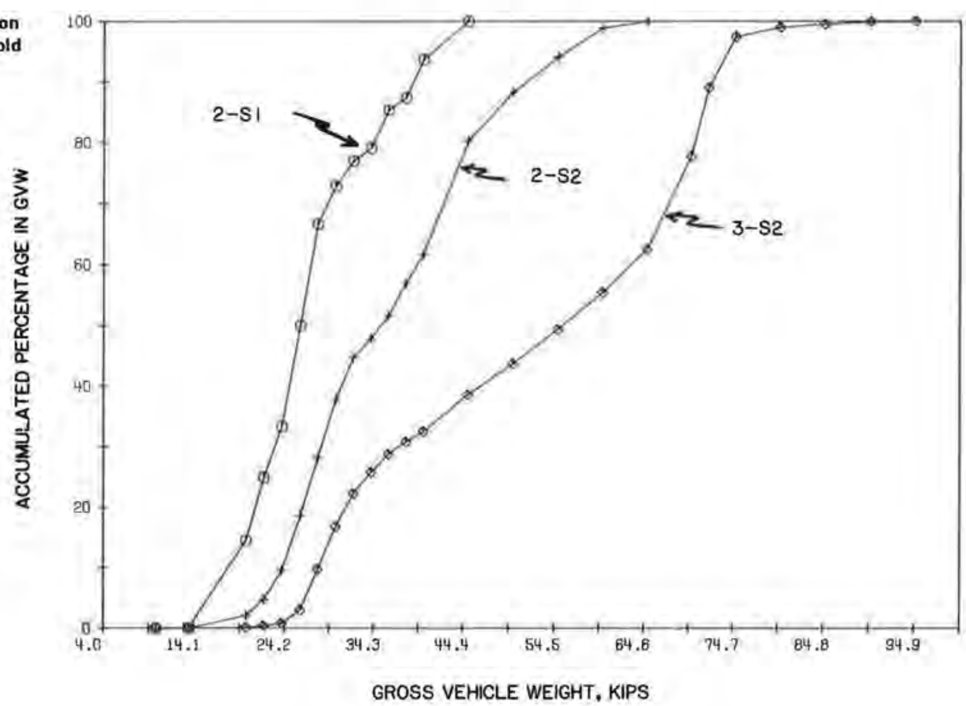


Figure 7. Cumulative GVW distribution of 2-S1, 2-S2, and 3-S2 trucks under old load limits (rural Interstates).



In many cases, trucks may "cube out" before higher axle load results. Furthermore, it would probably decrease the number of trucks necessary to transport a particular commodity, and, as a consequence, the number of load repetitions will decrease. On the other hand, higher load limits will result in heavier loads on trucks, which increases the ESAL for a particular truck.

Figure 8. Cumulative GVW distribution of 3-S2 truck for old and new load limits (shifting procedure).

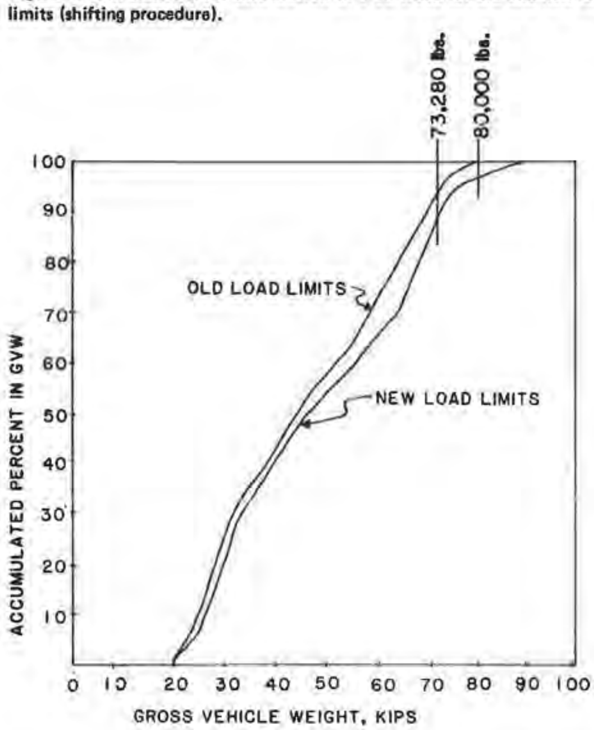


Figure 8 shows a typical shift of the GVW distribution of the 3-S2 truck by using the shifting procedure described above. As expected, the GVW distribution shifted toward higher loads. This results in additional payload carried per truck, and if the same types of trucks are used with higher loads, the life cycle of the pavements exposed to these loads will decrease because the damage per loaded truck increases exponentially as the payload increases linearly. In any case, the method gives the decisionmaker a tool to compare incremental damage due to a particular increase in load limits.

MAINTENANCE COSTS CONSIDERED

In this study the term "maintenance" refers only to those maintenance functions directly related to the pavement structure. Two types of maintenance operations were considered--routine and major maintenance.

Routine Maintenance

Routine maintenance is defined as the correction of pavement distress as it occurs at irregular time intervals. It includes all types of patching and sealing, repair of blow-ups, and all other operations related to the pavement structure during its life cycle. In this study, routine maintenance was estimated by using prediction models developed by Butler (14).

Major Maintenance

Major maintenance is defined as resurfacing of the pavement in order to bring the road surface back to its original, constructed condition. End-of-period maintenance done prior to the application of an overlay, such as patching, resurfacing, and wedging of rutted sections or removal of badly deteriorated pavements, is also included in this category.

Table 4. Range in increased pavement maintenance costs (resurface only).

	Area			
Type of Road	Northern	Central	Southern	System Total
Dollars per Lane Mile per Year				
Interstate	458.81-727.34	447.30-764.94	420.18-968.13	458.98-811.26
Primary	354.08-584.28	533.54-829.04	377.22-600.72	425.01-655.17
Secondary	234.68-494.60	261.29-682.77	204.87-374.31	212.14-489.92
Thousands of Dollars per Year				
Interstate	600.07-951.29	967.40-1654.38	491.31-1132.02	2129.64-3764.18
Primary	880.28-1452.57	939.92-1460.49	748.79-1192.44	2649.33-4084.04
Secondary	819.07-1726.23	1052.32-2749.79	857.78-1567.21	2482.99-5734.27

Table 5. Range in increased pavement maintenance costs (resurface plus routine maintenance).

	Area			
Type of Road	Northern	Central	Southern	System Total
Dollars per Lane Mile per Year				
Interstate	589.61-821.56	594.97-878.15	487.40-983.81	563.32-888.80
Primary	307.54-658.92	699.79-858.16	471.54-649.79	490.84-713.88
Secondary	301.57-543.49	433.62-747.34	273.11-446.47	313.20-543.76
Thousands of Dollars per Year				
Interstate	771.15-1074.52	1286.78-1899.23	569.91-1150.35	2632.33-4123.98
Primary	764.57-1638.13	1232.79-1511.79	936.01-1289.84	3059.68-4450.01
Secondary	1052.53-1896.87	1746.37-3099.84	1143.50-1869.34	3665.85-6364.44

Table 6. Estimated increased annual pavement maintenance costs for Indiana.

Type of Road	Increased Costs ($000 000s)	
	Resurface Only	Resurface Plus Routine Maintenance
Interstate	2.95	3.38
U.S. and state routes		
ADT >4000 (primary)	3.37	3.75
ADT <4000 (secondary)	4.11	5.02
Total	10.43	12.15

ECONOMIC COST PREDICTION DATA

Unit-cost information is needed for the different maintenance activities on a given pavement section. These include unit cost of asphalt concrete, granular material, patching, crack sealing, base and surface repair, and blow-up repair. The unit cost of these materials as well as typical maintenance costs were obtained from the Catalog of U.P.A. Prices for Roads and Bridges prepared by IDOH (15). These cost figures were given in terms of 1978 dollars.

The additional input parameters that affect economic predictions are (a) the interest rate used for economic analysis and (b) the length of the analysis period. A 20-year analysis period was used in this study.

Since changes in legal load limits will produce maintenance costs at different periods of time, it is necessary to convert these costs to equivalent costs at the same time basis. This is the reason interest rates are used in engineering economic analysis. In this study the routine maintenance and overlay costs were converted into an EUAC. A conservative interest rate of 6 percent was used in the economic analysis.

INCREASED PAVEMENT MAINTENANCE COSTS

The cost range presented here includes estimates of the added routine maintenance costs and resurfacing costs that would be required when the weight limits in Indiana were increased from 73 280 to 80 000 lb gross. These cost changes are directly attributed to load changes.

Tables 4 and 5 show the estimated increased pavement costs with and without routine maintenance. For practicality, these cost estimates are presented in two forms: total increase in maintenance costs per lane mile per year and total increase in maintenance costs per year. These estimates are based on a confidence level of 90 percent. The increase in maintenance costs for pavements in the state of Indiana can be expected to range between $10.43 million and $12.15 million annually (in 1978 dollars) as shown in Table 6.

SENSITIVITY ANALYSIS

A sensitivity analysis is the process by which a given variable is changed while the other factors are kept constant. This is done to check how sensitive the variable of interest is, which in this case is the increased pavement maintenance costs.

In this study a sensitivity analysis was performed on the price of asphalt concrete to check its effect on increased pavement maintenance costs. The prices of asphalt concrete used in this analysis were $20.00, $22.50, $25.00, $30.00, and $40.00/ton in place. From this analysis, it was found that resurfacing costs are directly related to asphalt-concrete prices. Routine costs, on the other hand, do not vary linearly with asphalt prices since the costs include many maintenance activities exclusive of overlay.

SUMMARY AND CONCLUSIONS

This paper describes the methodology that was used by the state of Indiana in evaluating the effect of increased truck weights on pavement maintenance costs. The factors as well as the assumptions used in this study were briefly discussed. Routine as well as major maintenance were covered along with the cost information necessary to perform the analysis.

Cost estimates were presented in dollars per lane mile per year and in dollars per year for Interstates and primary roads (U.S. and state routes carrying more than 4000 vehicles/day) and secondary roads (U.S. and state routes carrying less than 4000 vehicles/day).

The results of this study have indicated that both routine and major maintenance will increase if larger loads are permitted on Indiana highways.

In summary, an increase in truck weight limits from 73 280 to 80 000 lb gross will cause an increase in pavement maintenance costs for the total state mileage to range between $10.43 million and $12.15 million annually (in 1978 dollars). Statistically speaking, this estimate is based on a 90 percent confidence level.

County roads were not considered in this study, since factual information relating the pavement thickness and truck weights on the statewide county system is not available.

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Incremental Cost-Allocation Analysis of Bridge Structures

DAVID R. SCHELLING

Methodologies pertaining to the allocation of costs for bridge superstructure by the incremental design method are developed. Generalized design relations are defined as a function of vehicle classes and are applied to three typical bridge structures. Three alternative allocation methodologies, which depend on the bridge functions, are also defined and applied to determine the cost functions for an entire state building and maintenance program taken over a six-year period. The results from these three methods are then compared for accuracy and amount of work required to implement them into a cost-allocation project.

Cost-allocation studies have traditionally been used to provide a systematic and logical basis for relating highway tax structures to highway program costs. There is no single accepted highway cost-allocation methodology, and the results of these studies often vary widely, depending on the method used. This is because much controversy currently exists as to whether roadway-related construction costs are design or damage related. Regardless of these difficulties, there is no doubt that the proper allocation of costs is an extremely important function that can significantly influence the amount of monies available for a highway program.

The proper execution of a cost-allocation project involves the occasioning of costs to numerous elements contained within any building or maintenance program. Considered in this paper is the methodology for the incremental design and subsequent allocation of costs to the superstructure elements of highway bridges. Although the total cost of such elements is often low as compared with that of other elements of the typical highway program (such as highway reconstruction and drainage), these elements may compose a high percentage of the allocatable costs within the program.

Finally, it is felt that the allocation of costs to bridge structures should potentially be one of the more accurate of any of the highway-related allocation methodologies in that the design process for bridges is well defined and well understood. If inaccuracies do appear in the allocation process for bridge structures, they are attributable to factors aside from the design function. Such factors can include

1. Lack of time to perform a detailed incremental design over the full range of vehicles,
2. Allocation of costs based on a single bridge that is not representative, and
3. Allocation of costs by methods not related to design.

Defined below are those methodologies that have been used to occasion the costs for bridge superstructure elements for an arbitrary set of highway loadings. These methods are applied to the actual highway program in which the results of each are compared.

VEHICULAR LOADINGS

Bridge structures are designed to a standard set of vehicular loadings defined by the American Association of State Highway and Transportation Officials (AASHTO) (1). The loads specified are designated with an H prefix followed by a number that indicates the total weight of the truck in tons for two-axle trucks or with an HS prefix followed by a number that indicates the weight of the tractor in tons for tractor-trailer combinations. These H and HS truck loadings are placed on the spans to simulate the actual vehicles most encountered on the highway system along with the H and HS lane loadings to simulate a series of vehicles. Both the truck and lane loadings are placed on the bridge to produce maximum effects throughout the structure.

The three parameters that influence the level of stress on longitudinal members that compose the bridge superstructure are the gross vehicle weight (GVW), the axle loads, and the spacing between axles. AASHTO (1) specifies a fixed spacing between axles of 14 ft for the H truck and variable limits from 14 to 30 ft for the HS truck. These trucks are to be positioned on the span so as to give maximum stresses and deflections along with the associated lane loadings.

Vehicular Classification

The vehicles that use the Maryland (2) highway system are categorized into seven basic classifications, which can then be broken down by GVW group. A summary of such a classification is given in Table 1 where 59 GVW groups are distributed among the seven basic classes. As can be noted from the table, each GVW group is identified by its design axle loading and spacing.

Hand HS-Truck Correlation

It was first necessary to determine the relationship between the AASHTO Hand HS-truck loadings. This was done by placing each loading type on a series of simple span bridges that ranged from 42 to 400 ft in length, equating the maximum moments at the centerline, and performing the correlations by means of a straight-line least-squares fit.

AASHTO Truck and GVW Correlation

The correlation of the AASHTO truck types with the state GVW system requires that the effect of each of

Table 1. Correlation between state and AASHTO vehicle classifications.

Range No.	AASHTO Classification		State Vehicle Type (GVW in kips)									
	H	HS	Automobiles	Pickups and Vans	Buses	Two-Axle, Four-Tire	Two-Axle, Six-Tire	Three-Axle	Dump Truck	2S1	2S2	3S2
1	1.9	1.3				0-4						
2	3.9	2.6	X	X		4-8	4-8					
3	6.0	4.0				8-12	8-12					
4	7.9	5.3				12-16	12-16					
5	9.8	6.6				16-20	16-20	16-20			28-32 32-36	
6	11.9	8.0				20-24	20-24	20-24			36-40 40-44	
7	13.9	9.4				24-28	24-28	24-28		28-32	44-48 48-52	
8	15.8	10.7			X	28-32	28-32	28-32		32-36 36-40	52-56 56-60	36-40
9	17.7	11.9				32-36	32-36	32-36		40-44	60-64 64-68	40-44
10	17.8	12.0						36-40				44-48
11	18.1	12.2									68-72	48-52
12	18.8	12.7								48-44		
13	19.6	13.2										52-56
14	19.9	13.4							36-40			
15	20.0	13.5						40-44				
16	20.5	13.8								48-52		
17	21.5	14.5										56-60
18	21.7	14.6								52-56		
19	22.1	14.9						44-48				
20	23.0	15.5									60-64	
21	23.6	15.9						48-52				
22	24.1	16.3						52-56				
23	24.8	16.7									64-68	
24	26.7	18.0									68-72	
25	28.2	19.0								72-76	72-76	
26	29.7	20.0									76-80	
27	30.8	20.8							60-64[a]			

[a] Designed in range 26.

these loadings be equated for their effect on bridge structures. Specifically, each GVW weight group within each class is placed on a series of simple spans that range from 40 to 400 ft in length increments of 5 ft. From this, the maximum H or HS loading encountered in the entire range is taken as the equivalent loading.

Range Number

A convenience adopted here to identify the smallest increment of the index for the H and HS vehicles is the range number. The smallest increment for the index is used to ensure that the minimum overlap will exist between the AASHTO and GVW groupings. The resulting correlations, which relate the AASHTO truck types to the state vehicular classification system, are shown in Table 1 for the 27 vehicular ranges selected.

Finally, it should be noted that no vehicular loadings that exceed those used to design the actual structure should be used in the incremental design process even though significant numbers of higher loads are traveling on the system either by permit or otherwise. All designs to be used in determining the allocation of responsibilities should follow the actual design criteria used by the state as closely as possible. Thus, if a state chooses not to design to permit vehicles or illegal overloads, they should not be included in the allocation process either. If this were not done, the costs arising from the incremental design would exceed the actual costs of the structures.

The above correlations allow for the proper interfacing between the vehicular classification system used by highway design engineers and that required for the design of bridge structures. Other methods do exist that perform the same task (the GVW basis, for example), but they are believed to be less accurate in the correlations they yield than the method proposed here. Once the correlation process is complete, the AASHTO truck loadings can be used as the live loads as required for design.

INCREMENTAL DESIGN OF BRIDGE STRUCTURES

The incremental design of highway structures is based on the difference in design costs that results when various classes of vehicles are applied as loadings. The total cost (C_I) of any structural element I is given by the following expression:

$$C_I = \sum_{J=1}^{N} Q_{IJ} U_J \cdot I = 1, M \quad (1)$$

where M is the number of elements that make up a structure (e.g., deck, stringer, pier), and N is the materials used to construct the elements. From this, Q_{IJ} is the quantity of each Jth material for the Ith structural element and U_J is the unit cost for that material. Here, the quantity of material, say the volume of steel in a bridge girder, will vary with the classes of vehicles that act as loadings on the structure. When this quantity is multiplied by the unit cost, the total cost of the element will result. Then as the vehicular classes are applied incrementally, the result is those incremental costs that are attributable to any respective class that caused the cost difference. Thus, Q_{IJ} represents a quantity function dependent on the class of loading that is applied to a structural element.

This paper will deal only with bridge structures, which are composed of steel stringers that act either compositely or noncompositely with a reinforced-concrete deck. For this type of structure, the index I in Equation 1 is defined as follows: 1

= superstructure reinforced-concrete deck, and 2 = steel stringer. Accompanying these elements are the material definitions for the index J in Equation 1: 1 = reinforced-concrete in place, 2 = structural steel in place. The definition of the incremental costs is given as follows for these elements and materials.

Bridge Decks

The bridge-deck elements consist of the reinforced-concrete deck, which acts either compositely or noncompositely with the longitudinal steel beam elements and that nonstructural part of the deck that acts as a wearing surface. The cost of the deck element can be written by using Equation 1:

$$C_1 = Q_{11}U_1 \quad (2)$$

Here, Q_{11} represents the quantity of reinforced concrete ($Q_{12} \equiv 0$) and U_1 represents the unit cost of reinforced concrete in place, including the cost of steel reinforcement. The cost and quantity of the actual slab are given by the following:

$$(C_1)_D = (Q_{11})_D U_1 = D_D T_D U_1 \quad (3)$$

Here, $(Q_{11})_D = D_D T_D$, where D_D and T_D are the area (in plan) and the thickness of the slab for the actual bridge, respectively.

The quantity of reinforced concrete for the theoretical structure under the design loading is given by

$$(Q_{11})_D = k_1 d_D t_D \quad (4)$$

where d_D and t_D are the area (in plan) and the thickness of the slab for the theoretical slab, respectively. If this is equated to the quantity of the actual bridge in Equation 3, the constant k_1 can be defined as follows:

$$k_1 = D_D T_D / d_D t_D \quad (5)$$

This represents a form factor to account for differences between the actual and the theoretical slab designs.

The cost of any slab element $(C_1)_k$ is derived from the loading of the kth vehicle class and is given by

$$(C_1)_k = (Q_{11})_k U_1 = (D_D T_D / d_D t_D) U_1 d_k t_k = \alpha_1 d_k t_k \quad (6)$$

where d_k and t_k represent the area (in plan) and the thickness of slab under the kth design vehicular loading, respectively. The term α_1 represents a constant for each bridge and is represented by the following relation:

$$\alpha_1 = (D_D T_D / d_D t_D) U_1 \quad (7)$$

In order to determine the difference in the cost of successive slab designs for the kth and (K+1)th vehicle classifications, the following relation may be written:

$$(\Delta_1)_{k+1} = \alpha_1 (d_{k+1} T_{k+1} - d_k T_k) \quad (8)$$

It must be emphasized that the parameters d_k and t_k are functions of the kth vehicle loading since the plan area of deck is dependent on the length and width of the bridge, which in turn is dependent on the vehicle class (see Table 3). Further, the thickness is directly dependent on the axle shear loadings and the bending moment generated by the kth loading. However, for most slab designs, the resulting plan area and thickness of the theoretical bridge proportioned for the design vehicle coincide with those of the actual bridge. Thus, $d_D = D_D$ and $t_D = T_D$, which yields $\alpha_1 = U_1$ and allows Equation 8 to take the following simplified form:

$$(\Delta_1)_{k+1} = U_1 (d_{k+1} t_{k+1} - d_k t_k) \quad (9)$$

The basic design parameter for the deck element is the slab thickness, since the volume of concrete depends directly on this dimension. The procedures used in the determination of thickness follow the AASHTO (1) specifications for the design of composite or noncomposite steel or concrete bridge structures. Specifically, two criteria are followed, each of which yields a required slab thickness. These, along with other conditions that define the load-geometry relationship, are given as follows:

Design Functions

Summarized in Table 2 are a total of 12 functions (2) used to define the basic geometry of design limits. These reflect those policies that could be practiced if bridge structures were to be designed for the full range of vehicular classes defined in Table 1.

Bending-Moment Criterion

One criterion used to determine the thickness of slab is that which satisfies the bending moment if it is assumed that the slab is continuously supported over three or more stringers.

Shear Criterion

The second criterion that must be satisfied is that which provides for a slab thickness adequate to sustain the punching shear due to a wheel load.

Deck Design

The width, length, and thickness of the deck slab are determined from the maximum thicknesses obtained by using the bending-moment and shear criteria for the geometry and loading associated with the various classes of vehicles considered.

In order to illustrate the method and the results obtained from the incremental analysis, an example was selected that is considered to be representative of deck-replacement projects. The results from the analysis are shown graphically in Figure 1, where the slab thickness is given as a function of the vehicle range number. Here it can be noted that abrupt changes occur between ranges 2 and 3, where the 2-in wearing surface is applied.

Longitudinal Elements

Longitudinal elements are bending members that are assumed to consist of rolled standard W sections or plate girders that act compositely with the reinforced-concrete deck. The total cost of this element can be written as follows from Equation 1:

$$C_2 = Q_{22}U_2 \quad (10)$$

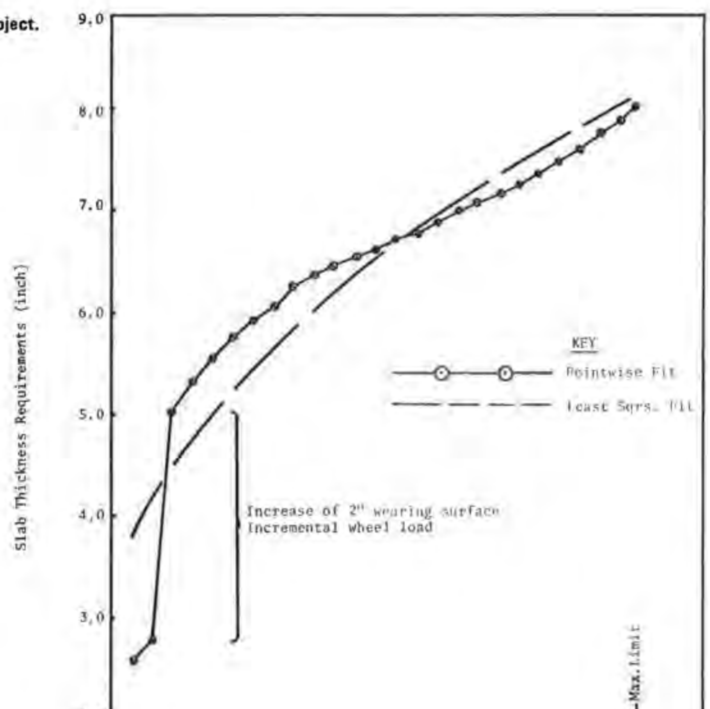
where $Q_{22} = 0$ (since no concrete exists in a steel stringer) and U_2 represents the unit cost of steel in place. The cost and the quantity of the actual structure are given by the following formula:

$$(C_2)_D = (Q_{22})_D U_2 = \left(\sum_{i=1}^{P} A_i S_i\right) DF(NS)_D U_2 \quad (11)$$

Table 2. Specification of bridge design functions.

Item	Description or Definition	Unit
1. Parapet function	Description: Relationship between GVW and weight per running foot ($W/_P$) of parapet, railing, and median. Assumption: Constant for all vehicle weights. Note: It is expected that any change in unit weight of parapet will be negligible.	Pounds per square foot
2. Vertical-clearance function	Description: Relationship between GVW and vertical clearance (H_v) for vehicle passage under a grade separation. Assumption: For all bridges, use a clearance of 8 ft for all vehicles equal to or less than H3.6 and 16 ft 9 in for all vehicles greater than H3.6.	Feet
3. Wearing surface	Description: Relationship between GVW and the unit weight of wearing surface (W_{ws}). Assumption: For all roads, H3 vehicle: $W_{ws} = 0$. For all roads, vehicles over H3 to HS20: $W_s = 25$ lb/ft^2 (equivalent to a 2-in depth concrete).	Pounds per square foot
4. Lane-width function	Description: Relationship between GVW and the lane width (H_L). Assumption: Lanes will be identical with those given for the highway. For all highways and GVW <10 000 lb, lane width = 11 ft; for GVW ≥10 000 lb, lane width = 12 ft.	Feet
5. Shoulder-width function	Description: Relationship between GVW and the shoulder width (W_s). Assumption: Shoulder width will be identical to that given for highway in cases where total deck width of hypothetical bridge is equal to or less than that of actual bridge. Here, for bridges on secondary roads, W_s = 6 ft for GVW <10 000 lb and W_s = 8 ft for GVW >10 000 lb. For bridges on primary and Interstate roads, W = 8 ft for GVW <10 000 lb and 10 ft for GVW ≥10 000 lb. For cases where hypothetical bridge deck width is greater than actual bridge deck width by using the lane-width function, lane-width function becomes W_s = 0.5 [actual deck width − (no. lanes) x (lane width)].	Feet
6. Slab-thickness function	Description: Relationship between GVW and slab thickness (t_s). Assumption: Given by current AASHTO specifications for design of reinforced-concrete deck slabs.	Inches
7. Stringer-spacing function	Description: Relationship between GVW and stringer spacing (S). Assumption: Stringer spacing nearest that given for existing bridge is used in design.	Inches
8. Length-to-depth ratio	Description: Ratio of bridge span length to depth of beam used in design process. Assumption: Maximum values of length-to-span ratio was held constant at 35 for all structures. Note: Value recommended by AASHTO is 25.	
9. Detail factor	Description: That factor (F_D) which when multiplied by computer dead load (consisting of the deck, stringer, parapet, railing, and wearing surface) will yield actual dead load of superstructure. This factor would typically account for connections, rebars, studs, etc. Assumption: Use 0.05 (5 percent) for rolled beams.	
10. Typical embankment slope	Description: Slope of embankment for a grade separation. Assumption: Use 2:1 or H_1 = 2 horizontal, H_2 = 1 vertical.	$H_1:H_2$
11. Cover plate	Description: Policy of whether cover plates will be used on rolled sections or plate girder bridges. Assumption: No cover plates were used per se in design of longitudinal beam elements. The steel material volumes for hypothetical structure were adjusted to reflect volumes of actual structure, which may include cover plates.	
12. Overhang function	Description: Relationship between GVW and overhang distance (H_0). Assumption: For vehicles from H 3 to HS 20 design overhang. For HS 20 vehicles, maximum of 3 ft 6 in.	Feet

Figure 1. Slab thickness requirements: deck-replacement sample project.



In Equation 11, the actual quantities of all steel are represented by the following:

$$(Q_{22})_D = \left(\sum_{i=1}^{P} A_i S_i\right) DF(NS)_D$$

where

- A_i and S_i = area and length of ith steel section, respectively, which compose the steel element;
- P = number of sections;
- DF = detail factor of bridge (to account for attachments, connections, etc.); and
- $(NS)_D$ = number of stringers of actual structure (which may differ from that for any theoretical structure).

The quantity of the stringer material $[(Q_{22})_D]$ for the theoretical structure under the actual bridge design loading is given by the following:

$$(Q_{22})_D = k_2 S_D a_D DF(NS)_D \quad (12)$$

where S_D and a_D are the length and the average cross-sectional area, respectively, of the stringer for the actual bridge design loading. If this is equated to the actual steel quantity given by Equation 11, the constant k_2 can be found:

$$k_2 = \left(\sum_{i=1}^{P} A_i S_i\right) S_D a_D \quad (13)$$

which represents a form factor to account for differences between the actual and idealized stringer designs.

The cost of any stringer element $[(C_2)_k]$ derived from the loading of the kth vehicle class is given by

$$(C_2)_k = (Q_{22})_k U_2$$

$$= \sum_{i=1}^{P} A_i s_i [(DF)U_2] S_k a_k (NS)_k / S_D a_D$$

$$= \alpha_2 S_k a_k (NS)_k \quad (14)$$

Here, S_k, a_k, and $(NS)_k$ represent the length, cross-sectional area, and the number of stringers under the kth design vehicle loading, respectively. The term α_2 represents a constant for each bridge and is given by

$$\alpha_2 = \left(\sum_{i=1}^{P} A_i S_i / S_D a_D\right)(DF)(U_2) \quad (15)$$

In order to determine the difference in the cost of successive stringer designs between the kth and (K+1)th vehicle classifications, the following cost difference may be written:

$$(\Delta_2)_{k+1} = \alpha_2 [S_{k+1} a_{k+1} (NS)_{k+1} - S_k a_k (NS)_k] \quad (16)$$

It must be emphasized here that the parameters S_k and $(NS)_k$ are functions of the kth vehicle. Here, the clearance and embankment slope both affect the length of the bridge. The roadway width affects the number of stringers as defined by item 7 in Table 2. These, along with the weight of the kth vehicle, greatly influence the resulting design area (a_k) of the steel section. The beam components are selected in accordance with the AASHTO specifications (1), where the moments of inertia determine the beam section. Specific design procedures are given as follows:

Design Function

Summarized in Table 2 are a total of the 12 functions (2) used to define the basic geometry and design limits for beam elements.

Structural Analysis

The AASHTO live loadings for the H and HS truck and lane loadings are used to obtain the maximum shear and moment envelopes along the bridge span. The distribution factors, moments of inertia, effective widths of deck slabs, dead loads, and modular ratios for n = 27, 9, and infinity as prescribed by the AASHTO specifications (1) are used. The basic analysis assumes that all beams are simply supported. Thus, where continuity exists between spans, simple beams are assumed. It is felt that this assumption will not result in a great degree of error in the volume of steel required for continuous structures since the k_1-factor at least partly compensates for the lack of continuity, fatigue details, and connections.

Member Selection

The members are selected on the basis of a required section modulus calculated by dividing the material allowable, taken as 55 percent of the yield point, into the maximum moment for [DL + (LL + I)] found within the span. The ratio of length to depth is used to determine the depth of the member (see Table 2). The results given for the designs cited herein were obtained from a computer program that has been used to design bridge structures (3).

A series of three sample (2) structures is given to illustrate the methodology and to indicate the wide variability of results obtained. The sample bridge structures defined in Table 3 were selected to yield the maximum, minimum, and representative levels of allocation of costs above the base structure. These are identified in Table 3 as structures 1, 2, and 3, respectively, along with a summary of the results of the cost-allocation process.

An example of the variation of the stringer area requirements is shown in Figure 2 for structure 1 as a function of the vehicle range number. It can be noted that the area increases stepwise, which is due to the selection of economic rolled shapes that suffice over a number of vehicle loading ranges. A continuous parabolic curve determined by the least-squares criterion is fitted to the area function obtained and is superimposed over the actual stepwise area requirements.

The total percentage of increase for AASHTO truck types for stringer and slab elements is shown in Figure 3 for all three sample structures. The results of structure 1, which represents the maximum allocation above the base bridge, lie below the results of all other examples. Further, the results of structure 2, which represents the minimum allocation, lie above all other curves. Finally, the results for structure 3, which represents the average bridge, lie unexpectedly close to the results of structure 2.

Another unexpected result of the incremental design of the sample structures is that the cost functions for the stringer, deck, and the sum of the stringer and deck are nearly linear for vehicle loadings above that point at which the bridge geometry does not change. The linear cost functions for the stringer, slab, and combined stringer plus slab are shown in Figure 4. Again, structure 1 lies below all other results, and structure 2 lies above all other results and is close to the results of structure 3.

Table 3. Definition of superstructure sample projects.

Item	Sample Structure		
	1 (maximum allocation)	2 (minimum allocation)	3 (representative allocation)
Design vehicle	HS 20	HS 20	HS 20
Structure type	Grade separation	Railroad type	River crossing
No. of lanes per bridge	2	2	2
Span length (span 2) (ft)	86.0	156.00	90.0
No. of stringers	6	6	6
Steel	A588 GR 50	A588	A588
Construction type	Composite	Composite	Composite
Slab thickness (in)	8.5	8.5	8.5
Deck width (ft)	40	43.2	30
Stringer spacing (ft)	7.33	7.63	5.75
Additional dead load (kips/ft)	0.5	0.5	0.5
Overhang width (ft)	3.27	3.00	2.23
Raised deck width (ft)	0.0	0.0	0.0
Haunch thickness (in)	2	2.0	2.0
Key	0.0	0.0	0.0
Fillet angle (degrees)	90	90	90
Sidewalk dead load	0.0	0.0	0.0
Sidewalk live load (lb/ft^2)	0.0	0.0	0.0
Detail factor	1.05	1.05	1.05
Unit cost (1980)			
Steel ($\$/ft^3$)	281	318	281
Concrete ($\$/yd^3$)	338	383	338
Stringer			
Original cost ($)	154 000	766 000	2 217 250
Theoretical cost ($)	113 152	845 756	1 573 176
Difference (%)	26.5	10.4	29
To first increment (%)	13.5	83	84.2
Allocatable to trucks (%)	86.5	17	15.8
Deck			
Original cost ($)	117 610	350 710	
Theoretical cost ($)	61 052	237 287	
Difference (%)	48.1	2.3	
To first increment (%)	19.9	33.8	
Allocatable to trucks (%)	80.1	66.2	
Total			
Original cost ($)	271 610	1 116 710	2 230 750
Theoretical cost ($)	174 204	1 083 043	2 019 949
Difference (%)	35.9	3	9.4
To first increment (%)	15.7	72.2	72.7
Allocatable to trucks (%)	84.3	27.8	27.3

ALLOCATION METHODS

The techniques that have been used to allocate the construction costs of superstructure elements to a generalized set of vehicular loadings fall under one of the following four basic methodologies:

1. Full-design method,
2. Representative-bridge method,
3. Semistatistical method, or
4. Heuristic methods.

All these methods can use, to varying degrees, the incremental structural design procedures outlined above. However, the results obtained from using any one method can differ considerably from those from another. The methods and results obtained for these methods are given in the following paragraphs.

Full-Design Method

This method uses all bridges designed within a representative time period to reach the cost-distribution function. Because so many bridges are generally involved, the design procedure often must be simplified. The methodology outlined above in the section on the incremental design of bridge structures was applied to all projects that involved the construction of bridge superstructures in Maryland (2) during a six-year base period (1978-1984). Here, all new construction and rehabilitation projects were considered in the incremental design process. From the summary tabulated below, it can be noted that 105 spans were constructed during the period, which entailed 2730 discrete designs (since 26 load increments are required).

Item	Amount
No. of spans on Interstate system	20 (19 percent)
No. of spans on primary system	36 (34 percent)
No. of spans on secondary system	49 (47 percent)
Total no. of spans	105
No. of spans over rivers	73 (70 percent)
No. of spans over roads	32 (30 percent)
Total no. of spans	105
Total length of all spans (ft)	10 063
Avg span length (ft)	95.8
Total no. of contracts	10
Total cost (actual) ($)	63 815 749
Total cost (computed) ($)	22 038 633
Cost to base vehicle (%)	
Avg	33.0
Maximum	34.2
Minimum	31.3
Type of construction	All composite

The total cost of the superstructure elements during the period was $63 815 749, which involved the construction of 10 063 linear feet of bridge roadway. The curve representing the distribution of all costs relative to the design and rehabilitation of superstructure over the six-year period is given in Figure 5.

It should be pointed out that the cost function given in Figure 5 represents the percentage of the superstructure cost that must be borne by any given AASHTO truck. The responsibility determined by the cost-allocation process involves forming differences between subsequent vehicle ranges and distributing them by means of some allocator (say, vehicle miles of travel) to those vehicles that fall into that AASHTO weight grouping.

Representative-Bridge Method

As the name implies, this method requires that a representative bridge structure be selected and subjected to a detailed incremental design in order to formulate the cost function. This is then used as the cost function for all bridges within the representative period. As was indicated previously, a considerable spread can result for the allocation function for different projects. The degree of this spread can be noted in Figure 3, where as much as a 50 percent difference can occur. Further, the selection and the incremental design of the representative sample structure thus resulted in an allocation function that was slightly below that which represented the minimum allocation for vehicles above the base vehicle.

The cost-allocation project conducted by the Federal Highway Administration (FHWA) (4,5) used the representative-bridge method where bridges were selected to represent construction types for both grade separations and river crossings. The allocation functions derived from the detailed design process resulted in a spread of about 10 percent between bridges. It must be noted that great care was taken in this study in the selection of the representative bridges. Further, the cost factors were altered to give a true representation of the type of project the bridge was to reflect.

The representative-bridge method is tempting in that the incremental design process is required only on one structure and, indeed, the method is the most popular one currently in use. However, unless great care is taken in the selection of the representative

Figure 2. Stringer area requirements for sample structure 1.

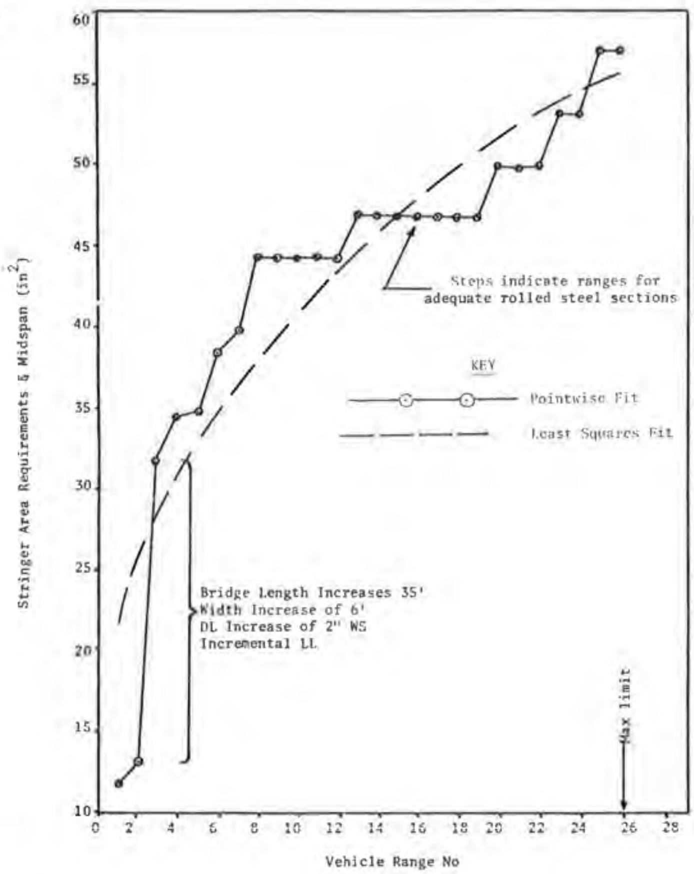


Figure 3. Added stringer and deck cost for all AASHTO loadings.

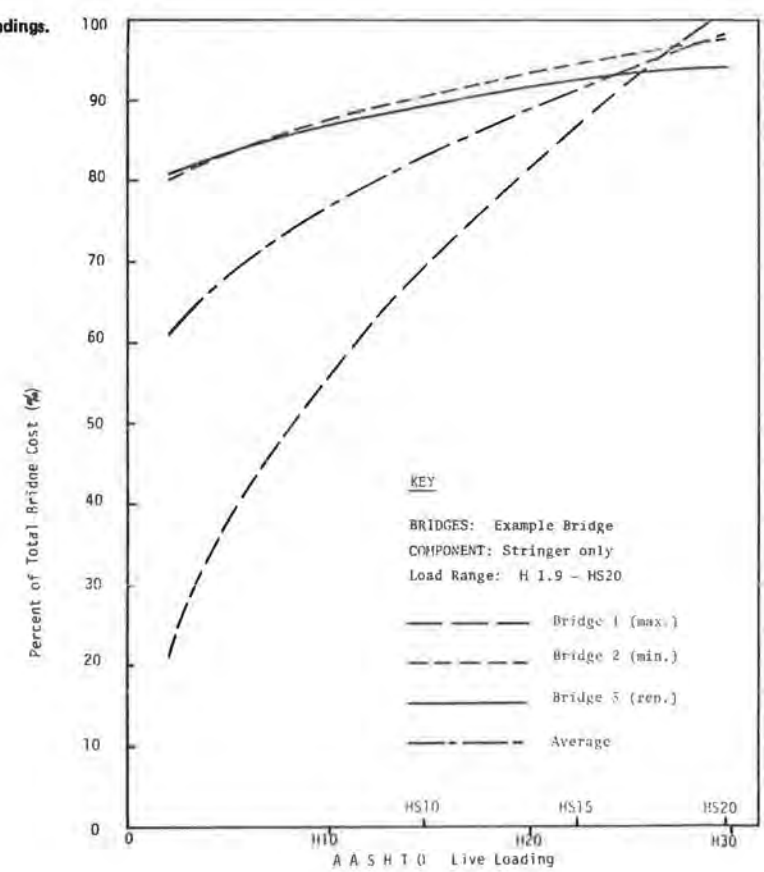


Figure 4. Added stringer cost over linear range AASHTO loadings.

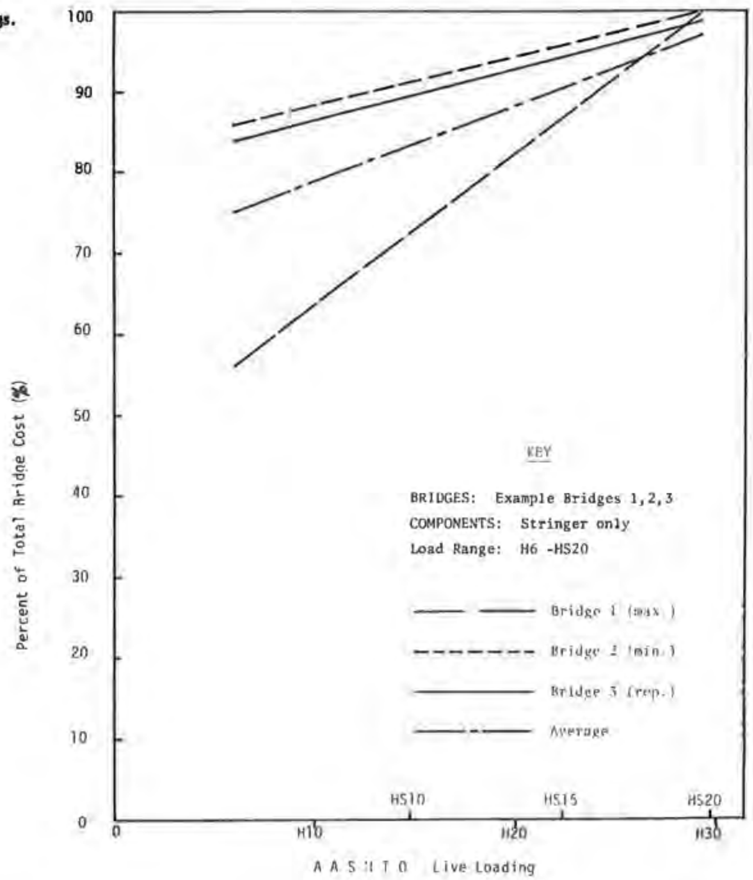


Figure 5. Comparison of cost distribution methodologies for narrow bridge.

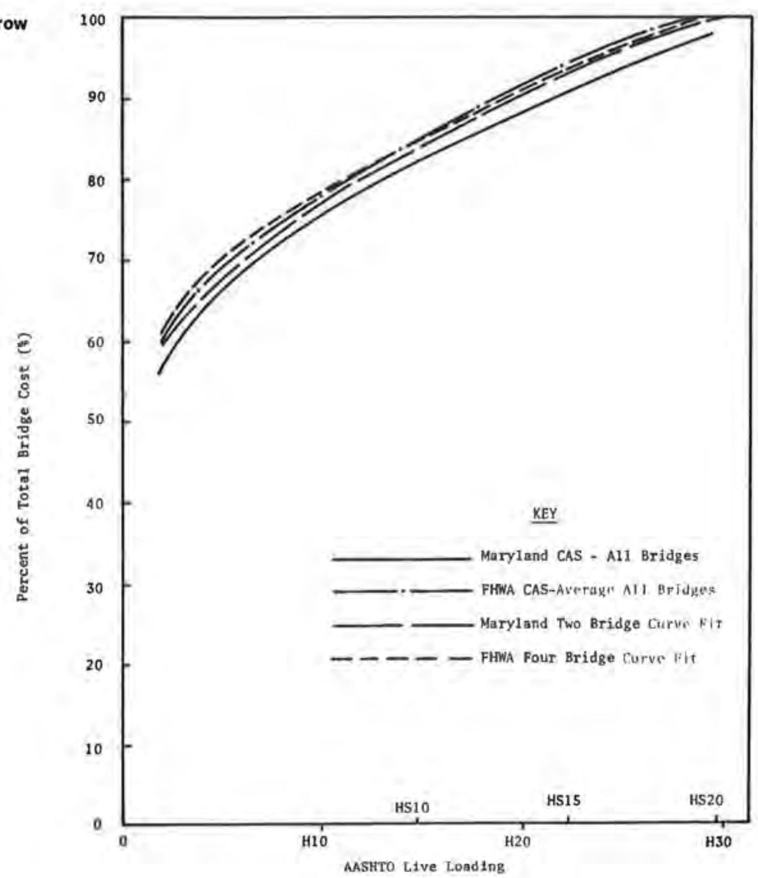


Table 4. Summary of methods.

Method	No. of Designs Required	Accuracy Expected	Design Mode
Full design	Many (3730)	Excellent	Some approximations used in design process
Representative bridge	Few (26)	Variable (10-50 percent)	Generally a detailed design process
Semistatistical	Few (3)	Excellent (4 percent)	Can be as detailed a design process as required
Heuristic	None	Unknown	Generally no design used

structure, the allocation function that results from the incremental design of the structure will differ significantly from that obtained from an analysis of all superstructure elements. If the structure is selected with care, results are good, as indicated by the relatively low spread obtained in the FHWA study (4,5).

Semistatistical Method

This method uses a combination of design and statistics to arrive at the allocation function. It attempts to minimize the possible spread by performing incremental designs on more than one representative structure. The steps are given as follows:

1. Select two or more structures that are considered representative of those bridges that the allocation function is to represent;
2. Design the representative structures for the minimum vehicle in order to determine the base facility by using all the geometrical functions as necessary;
3. Average the results obtained for the base facility as a percentage of the total costs expended for original construction; and
4. Fit a parabola through the percentage obtained in step 3 and 100 percent for the design vehicle by using the method of least squares. The parabola should be of the form $a + b\ (x)^{1/2}$, where a and b are constants obtained from the least-squares analysis and x represents the live loading (such as the range number, the AASHTO vehicular index, etc.). This method was used both for the sample structures representing Maryland bridges and for those used in the FHWA cost-allocation study. The results of this relatively simple method yield the curves given in Figure 5. Assuming that the solid curve representing all bridges in Maryland is the most correct, a curve fit that uses only sample structures 1 and 2 yields results within about 2 percent of those obtained for all bridges; the resulting curves for the FHWA bridge averages are all within about 4 percent above that given by Maryland study results. The allocation functions for any one of the Maryland or FHWA bridges all lie considerably outside these results.

Thus, the use of a parabolic curve positioned by the least-squares criterion through points obtained for a few different structures appears to be much more accurate and much less effort than performing a detailed incremental design over many steps for one representative bridge structure.

Heuristic Methods

These methods generally involve basing the allocation function on various relationships believed to be representative. Relationships such as the proportionalities between the cost and the maximum moment in simple spans or the combination of dead load and live loading to the cost functions are typical. In defense of such practices, it can only be said that at least they are based on a consistent criterion arrived at by engineers generally knowledgeable in structural design methods rather than those conjured by legislators steeped only in the knowledge of law.

SUMMARY AND CONCLUSIONS

The procedures used for the allocation of the costs for the construction of bridge superstructures are highly variable and subject to wide variations in the results they yield. Identified here are four basic methods that traditionally have been used to determine the allocation function. These are summarized in Table 4 along with the benefits and drawbacks of each. As can be noted, the semistatistical method seems to be the most attractive; good accuracies are attained with relatively few designs.

It must be pointed out, however, that the cost-allocation process is not so much a science as an art. For this reason, it is extremely difficult to determine accuracy, since no one true answer exists. However, it is possible to examine the methods, as was done in this study, where the variances of the results are compared to some norm.

Finally, it must be concluded that greater standardization should be sought in the definition and specification of the design parameters that relate to the incremental design of bridge superstructure. If the state design agencies are to be the basic source of expertise in this area, they must be given better guidelines to follow from AASHTO. This will allow the results forthcoming from any state-generated cost-allocation analysis to better withstand the political pressures that seem to be inevitable.

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Abridgment

Comparison of Standard Incremental and Relative-Use Methods of Highway Cost Allocation

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As highway costs increase more rapidly than user revenues, it is clear that most states must increase user taxes to prevent further deterioration of their roadway systems. As user tax rates increase, state highway and elected officials should become more concerned with the equity of their tax structure. Recently many engineers and economists have questioned the standard incremental method of highway cost allocation, used by most states for several decades to determine the cost responsibilities of different vehicle groups. This study developed a relative-use method, partly based on the methodology developed by the Federal Highway Administration for the national cost-allocation study completed in 1982. The method presented in this study uses the original equations from the American Association of State Highway Officials road test to develop the relative use or damage associated with a single repetition of a given axle loading and then aggregates the use factors to the vehicle classes on the highway system. The new methodology as well as the standard incremental method were applied to Maryland highways, roads, and streets. Although both methods are cost occasioning in their conceptual framework, the relative-use method assigns more than twice the cost responsibility to heavy vehicles and subsequently reduces the responsibility of lighter vehicles when compared with the standard incremental method. The attempt was not to support either method nor to advocate a cost-occasioning method over marginal cost pricing; rather the paper develops a supportable method and presents the type of results obtained by its application to a typical state highway program.

By most estimates, the cost during the next 10 years to rehabilitate the nation's roadway systems will be greater than $0.5 trillion. These costs, borne solely by the public sector, will necessitate significant increases in highway user taxes and fees, since existing tax rates, if unchanged, will generate about one-third of the needed revenue. Such increases should necessarily increase public decisionmakers' concern with the equity of the proposed tax structure.

Highway cost-allocation studies are used to compare the share of user taxes paid by various classes of vehicles against the costs of highway construction and maintenance that may be attributable to each group. The results of a cost-allocation study can provide a basis to adjust total highway user revenues equitably by increasing (or decreasing) user taxes on specific vehicle groups that may be paying less (or more) than their equitable share.

This report describes the comparison of two distinct cost-allocation methodologies as they were applied to the state of Maryland; one is the standard incremental method (SIM), used extensively in many state allocation studies for more than 30 years, and the second is the relative-use method (RUM), developed for this study (1). The latter method uses partly, as a basis, the consumptive-model framework developed by the Federal Highway Administration (FHWA) for the national cost-allocation study completed in 1982 (2). Some significant changes in the FHWA method were made and considerable adaptation was necessary to apply the method to the Maryland state systems.

OBJECTIVE

The objective of this paper is simply to present and compare the results of the application of these two methods. We do not choose, at this time, to commit ourselves to which, if either, of the two methods is more correct. Nor do we wish to imply that any cost-occasioning methodology is in general necessarily the best way of pricing highway use. In fact, it can be argued soundly that society's interests can be achieved better by the implementation of some efficiency pricing mechanism, that is, some type of marginal cost pricing.

Nonetheless, it is clear that most states, with few if any exceptions, will continue to use cost-occasioning methods, and it is also clear that dozens of states will face a situation similar to the one Maryland faced last year. Thus, in the same way that the federal study in the early 1960s laid the framework for the incremental method, which was subsequently adopted by many states, the 1982 federal study will also be considered by many state highway agencies as an alternative allocation procedure.

INPUT DATA

Highways, Roads, and Streets

Before the two methods and the subsequent results of their application are described, it is necessary to present those costs that are involved. To arrive at a representative annual cost figure, the Maryland State Highway Administration (MSHA) decided to use the average of the actual expenditures for FY1979 through 1981 and the approved program costs for FY1982 through 1984.

Because of the different vehicle mix and roadway design specifications for different subclasses of the highway system, 10 different classes were analyzed: Interstate rural and urban; primary rural and urban; secondary rural and urban; county; and municipal freeway, arterial or collector, and local. In turn, the expenditures for each class were further subdivided into those costs from each of the two sources of funds--federal and state. An aggregated summary of these costs by major highway classification is presented below:

	Avg Annual Cost ($000 000s)		
System	State User	Federal Aid	Total
State highway	1.518 74	1.068 13	2.586 87
County road	0.654 82	0.021 24	0.676 06
Municipal street	0.741 08	1.853 98	2.595 06
Total	2.914 64	2.943 35	5.857 99

The costs of each roadway system were again further subdivided into seven major work items: right-of-way, grading and drainage, base and surface, shoulders, maintenance, administration, and other.

Vehicle Classification

In addition to the cost data, the second major input is vehicle miles of travel (VMT) for the various types of vehicles in the vehicle fleet. VMT data for 69 separate type and weight groups were assembled for each of the 10 roadway classes. In addition, loadometer data were collected to provide the distribution of axle loads for all vehicle groups. For the final reporting of cost responsibilities, the 69 type and weight groups were compressed into 29 groups.

Table 1. Sample PCE factors.

Vehicle Type	Highway System Class: Interstate Rural	Interstate Urban	Secondary Rural	Secondary Urban	Municipal Arterial or Collector	Municipal Local
Automobile	1.00	1.00	1.00	1.00	1.00	1.00
Bus	1.30	1.54	1.60	1.30	1.30	1.40
Single-unit truck						
2A, 4T	1.09	1.11	1.14	1.20	1.20	1.20
2A, 6T	1.15	1.28	1.20	1.14	1.14	1.30
3A	1.30	1.32	1.50	1.20	1.20	1.48
Combination truck						
2S-1	1.30	1.37	1.48	1.54	1.54	1.48
2S-2	1.45	1.56	1.72	1.81	1.81	1.72
3S-2	1.70	1.87	2.12	2.26	2.26	2.12

ALLOCATION METHODOLOGIES

SIM and RUM are described in detail in the final report (1). Only the major differences between the two methodologies will be discussed in this paper.

Both methods are based on a cost-occasioning framework. That is, each vehicle group is considered responsible for the costs associated with those facilities or portions of facilities that are necessary to accommodate that particular vehicle group. Those facilities, or portion thereof, that are not attributable to any specific vehicle group and are indeed used by all vehicles are considered as the base facilities. These costs, sometimes mistakenly referred to as "common" costs, are shared by all vehicle groups. MSHA determined that the base facility was the facility necessary to accommodate a vehicle with a maximum axle load of 3000 lb. The remaining costs are attributed to vehicles with characteristics that require facilities that are thicker, wider, higher, and the like than the base facility.

SIM Allocators

For base and surface costs, SIM uses the proportion of total axle miles, with tandem axles considered as one axle, as the intraincremental allocator for each additional increment of thickness (10 thickness increments) and the base-facility thickness. This allocator--axle miles--was also used as the allocator for all costs associated with the maintenance of the base, surface, and shoulders. For all other costs, unweighted VMT was used as the allocator.

RUM Allocators

RUM uses two allocators that differ substantially from those used in SIM. For all directly nonweight-related costs, the RUM intraincremental allocator is passenger-car equivalent weighted VMT (PCE-VMT). The concept of PCEs is based on the relative reduction of level of service of a roadway, first because it is larger and requires more space than an automobile and second because, due to its high ratio of weight to horsepower, it accelerates more slowly, slows on grades, and the like. These PCE factors are a function of the vehicle traffic and roadway characteristics and reflect the results of recent extensive FHWA-contracted research. Table 1 presents a sample of the PCE factors for major visual classifications of vehicle types.

The assignment of cost responsibility occasioned by weight differs radically from SIM. RUM allocates weight-related costs on the basis of relative use or damage sustained through the cumulative repetitions of axle loadings attributable to the various vehicle type and weight groups. The relationship between this relative-use factor and axle loads is based on the pavement design equations developed from the road test of the American Association of State Highway Officials (AASHO). From the MSHA-supplied design criteria, the thickness and layer coefficients are used to compute the structural number. This in turn is used along with the axle load and serviceability index to compute the number of repetitions of that specific axle load to produce failure. The inverse number of repetitions can be defined as the use or consumption caused by a single repetition of that axle load. From loadometer data, the distribution of axle loads for all 69 vehicle type and weight groups is known. Since the use or consumption due to any particular axle load is known, there is no need to compute equivalent single axle loads (ESALs). The use assigned to each vehicle group is the aggregation of the damage of each repetition of the actual over-the-road axle loads. To demonstrate the effect of the relative-use factor, consider the example of rural Interstate highways in Maryland. The annual travel by automobiles is 1164.8 million vehicle miles and that by 78 000+-lb combination trucks is 102 million miles out of a total 1672.1 million miles traveled by all vehicles. However, because the relative use attributed to the heavy axle loads of the truck is so much greater than that attributed to the axle loads of the automobile, it results in a much greater assignment of costs to the 78 000+-lb truck:

Vehicle Type	VMT (%)	Responsibility (%)
Automobile	69.7	0.3
Combination truck (78 000+-lb)	6.1	41.8

In other words, of the weight-occasioned costs of rural Interstate highways, automobiles are responsible for about one-half of 1 percent, whereas the single class of trucks, the 78 000+-lb combination truck, is responsible for almost 42 percent.

ALLOCATION BY WORK ITEM

A detailed description of the breakdown between base facility and occasioned costs is presented in the final FHWA report (1). In general, except for the different allocators, the two methods follow standard cost-allocation procedures. A great difference was in the allocation of costs associated with reconstructed pavements and pavements that had major repairs. There is considerable controversy about the damage done to pavements as a result of the environment. Different pavement experts can effectively argue that the environment is responsible for zero to 50 percent of pavement damage. The study team decided, based on input from the FHWA, that 25 percent of pavement damage was due to environmental factors and that the remaining 75 percent was weight related. Accordingly, in RUM 25 percent of the costs of reconstructed pavements and pavements that had major repairs was assigned to the base facility and allocated (as were all base-facility costs) to all vehicles in proportion to their share of the total PCE-VMT, and all remaining costs were considered weight related and allocated to all vehicles according to the relative-use factor. In SIM these costs were allocated based on 11 increments of thickness in the same manner as new pavements.

A second difference was in the allocation of maintenance costs. In SIM, all maintenance costs were considered part of the base facility and were allocated on the basis of VMT, except for those costs associated with the maintenance of the base,

Table 2. Average annual roadway costs.

Work Item	Cost ($000 000s) Incremental	Relative Use
Base and surface		
Base	0.192 98	0.095 87
Occasioned	0.095 72	0.192 83
Subtotal	0.288 70	0.288 70
Grade and drainage		
Base	0.191 17	0.191 03
Occasioned	0.017 02	0.017 16
Subtotal	0.208 19	0.208 19
Shoulder		
Base	0.027 30	0.027 26
Occasioned	0.022 19	0.022 23
Subtotal	0.049 49	0.049 49
Other		
Base	0.750 40	0.750 40
Occasioned	0.000 27	0.000 27
Subtotal	0.750 67	0.750 67
Special (occasioned)	0.014 35	0.014 35
Maintenance		
Base	0.906 80	0.968 72
Occasioned	0.317 96	0.256 04
Subtotal	1.224 76	1.224 76
Structures		
Base	0.227 76	0.222 82
Occasioned	0.150 71	0.155 65
Subtotal	0.378 47	0.378 47
Total	2.914 63	2.914 63

surface, and shoulders, which were allocated on the basis of axle miles.

In RUM, however, maintenance costs were divided into two groups--those that correct damage that is judged to be weight or size related and those that are judged to be a part of the base facility. The judgment as to which group each cost belonged was mainly subjective but relied on the accumulated expertise of MSHA maintenance engineers. Examples of those types of maintenance items that were judged to be weight related were continuous patching with bituminous concrete, deep patching, major repairs to bridge decks, and the like. Such items as joint filling, spot patching, and curb and gutter repair were judged to be not weight related. Since it was assumed that some of the weight-related repair costs were due to environmental causes, 25 percent of this group of costs was allocated on the basis of PCE-VMT and the remaining 75 percent by the relative-use factors. Those costs that were assumed not weight related were allocated in the same manner as other base-facility costs.

A stratification of the costs for all roadway systems by (a) work item, (b) type of cost (base facility or occasioned), and (c) allocation method is given in Table 2. Except for base and surface costs where RUM assumes that a large percentage of the costs for reconstructed pavements are occasioned, there is little difference between the two allocation methods. The greatest impact on the resulting responsibilities is clearly due to the differences in the allocators.

RESULTS

Average annual program costs for each highway system were allocated to 69 different vehicle type and weight groups. These groups were compressed into 29 groups. The study team investigated two revenue bases: (a) state-generated revenues only and (b) federal and state revenues combined. In turn, two sets of system costs were analyzed for each revenue base: (a) state highway system only and (b) entire roadway system (state, county, and municipal). The study team decided to analyze these four separate scenarios for several reasons. Although the state cannot affect changes in the federal user tax structure, these taxes are indeed paid by Maryland citizens and businesses, and consequently both revenue bases should be analyzed. Likewise, although the state cannot directly affect the type of expenditures made by counties and municipalities, nonetheless user tax revenues are passed through the state to the subordinate jurisdictions and therefore expenditures from user-generated revenues made on the entire system, as well as on the state system, should be analyzed and presented to state officials.

The results of all the scenarios for all vehicles cannot be presented here; however, Table 3 presents, as an example, the results of the analysis for the allocation of state revenues for all roadways and for state-owned systems. It is evident that the differences between the two methods are quite large. RUM, when compared with SIM, clearly results in significantly larger cost responsibilities for heavier vehicles and smaller responsibilities for lighter vehicles. For vehicles with high axle loadings, combination trucks, and dump trucks, RUM results in a two to three times greater responsibility than SIM. These results vary somewhat for each scenario due to the differences between vehicle mix and construction and maintenance program for each system and due to the different funding formulas for different programs. Nonetheless, the trend is clear: as axle loads increase, the cost responsibilities increase more rapidly. These differences in responsibilities, although large, are not unexpected, since RUM directly assigns costs as a function of the relative use or damage occasioned by axle loading as determined by the AASHO road-test equations.

Table 3. Comparison of cost responsibilities.

Vehicle Type	Responsibility of All Systems (%) SIM	RUM	Responsibility of State System (%) SIM	RUM	Current User-Tax Responsibility (%)
Automobile	71.26	60.22	67.19	55.99	67.39
Pickup, van	12.16	10.82	13.26	11.78	13.49
Bus	1.06	2.14	0.81	1.17	0.89
Single-unit truck (lb)					
10 000	1.42	1.46	1.56	1.64	1.47
14 000	0.15	0.15	0.17	0.17	0.16
18 000	1.36	1.51	1.50	1.64	1.52
22 000	0.45	0.56	0.50	0.59	0.56
26 000	0.82	1.12	0.92	1.17	1.01
30 000	0.34	0.56	0.38	0.55	0.38
34 000	0.96	1.70	1.10	1.84	1.31
38 000	0.42	0.94	0.47	0.92	0.56
42 000	0.05	0.08	0.06	0.10	0.08
46 000	0.11	0.18	0.13	0.22	0.17
50 000	0.04	0.06	0.04	0.07	0.06
54 000	0.02	0.05	0.03	0.05	0.03
56 000	0.39	0.71	0.47	0.81	0.58
Subtotal	6.53	9.08	7.33	9.77	7.89
Dump truck (lb)					
40 000	0.14	0.45	0.15	0.39	0.23
65 000	1.13	3.35	1.33	3.43	1.86
Total, single-unit truck	7.80	12.88	8.81	13.59	9.98
Truck tractor (lb)					
40 000	0.15	0.21	0.19	0.23	0.16
44 000	-	0.01	0.01	0.01	-
48 000	0.02	0.04	0.02	0.04	0.01
52 000	0.33	0.60	0.40	0.68	0.33
56 000	0.13	0.26	0.15	0.27	0.12
60 000	0.09	0.16	0.12	0.20	0.11
64 000	0.05	0.09	0.06	0.11	0.06
68 000	1.63	3.16	1.94	3.34	1.71
72 000	0.04	0.08	0.05	0.09	0.04
76 000	2.04	3.98	2.44	4.35	2.22
79 000	3.24	5.35	4.55	8.15	3.49
Total, truck tractor	7.72	13.94	9.93	17.47	8.25

Of course, in a state highway program, only a small percentage of the total program dollars is spent on new construction and major rehabilitation (about 10 percent in Maryland), and in fact only 22 percent of all roadway costs were judged size and weight related. Consequently, automobiles, pickup trucks, and vans are clearly assigned a large majority of total program costs.

Table 3 also presents a comparison of the two sets of responsibilities with the percentage of the current total Maryland user-tax payments. Thus, in Maryland, the allocations determined by the application of each method result in distinctly different policy implications. When the SIM results are used, automobiles pay slightly less than their fair share, whereas the RUM results indicate that automobiles pay much more than their fair share. For heavy combination trucks, the RUM results indicate that a doubling of the annual user taxes is appropriate in terms of equity.

CONCLUSIONS

It is not the purpose of this paper to argue which cost-allocation methodology is best; rather it is to discuss the basis of a new method, RUM, and present a comparison of the assigned cost responsibilities. Both methods have strong proponents among engineers and economists, and until a consensus determines which method is best, this subject will remain controversial.

Both of these methods, however, in their most basic framework use a cost-occasioning theory. That is, each vehicle group is assigned a share of the total roadway cost based on the costs caused or occasioned by the group. Neither method attempts to address the efficiency issue. It is clear that efficient pricing of the roadway system would rely on an application of some type of marginal cost pricing. However, until an implementable (politically and technically) marginal cost-pricing plan is developed, states will no doubt rely on a cost-occasioning methodology.

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Use of Multiple-Time-Series Framework to Identify and Estimate Quarterly Model of Gasoline Demand

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A portion of the work performed in developing a revenue-forecasting model used by the Wisconsin Department of Transportation is reported. A single-equation econometric model of gasoline demand is developed and tested by nesting the model within a more general multiple-time-series framework. Use of an appropriate disturbance structure for the model has significant effects on the model's fit and estimated elasticities. The results also indicate that direct and indirect models of gasoline demand are both consistent with the data. The forecasting performance of alternative specifications of the gasoline demand model is evaluated, and it is shown that the multiple-time-series specifications are clearly superior. These results support the use of a multiple-time-series framework and detailed diagnostic checks when time-series data are used to estimate models of gasoline demand and other economic processes.

Forecasting the demand for gasoline is of obvious importance to sound transportation planning at the state level. Over the last 10 years, considerable attention has been directed to this issue. The bulk of the research has concentrated on the identification and estimation of econometric models of demand. Typically, these models have been estimated by using either time-series or cross-sectional time-series data. Early models were often based on annual observation periods, but models based on quarterly or monthly observations are becoming increasingly common. Recent surveys of the literature on gasoline demand modeling are contained in papers by Beaton and others (1) and by Hartman, Hopkins, and Cato (2).

For the most part, the gasoline demand models in existence today have been developed by using a traditional econometric modeling approach. There has been no systematic attempt to integrate econometric and time-series-analysis techniques. In recent years, a number of authors [Zellner and Palm (3), Wallis (4), and Howrey (5)] have shown that structural econometric models are special cases of more general multiple-time-series processes. Howrey (5, p. 278) indicates the importance of this result by stating that "if the assumptions of a structural econometric model place restrictions on a more general time series model, the time series model will provide a vehicle to test the validity of those restrictions, and hence the adequacy of the econometric model." By testing restrictions in this way, it is possible to develop models that use more of the information contained in the sample data. This approach should lead to models with improved specifications and forecasting properties.

At the Wisconsin Department of Transportation (WisDOT), a multiple-time-series framework has been adapted for use in modeling and forecasting quarterly gasoline demand (highway). The results of the modeling effort highlight the advantages that a multiple-time-series framework has in terms of model identification and forecasting. The purpose of this paper is to briefly discuss the approach used and the results obtained in developing this model. The approach is easily implemented (6) and should be of value to any researcher using time-series data to model and forecast economic processes. In Wisconsin, a multiple-time-series framework has also been used to develop quarterly models for automobile and truck sales, demand for special fuel (highway), and highway construction cost inflation. A detailed study of monthly gasoline demand has been made by Wolfgram (7).

STRUCTURE OF MULTIPLE-TIME-SERIES MODELS

A linear multiple-time-series process can be represented as follows:

$$\underline{\Phi}(B)\underline{Z}_t = \underline{\Theta}(B)\underline{a}_t \quad t = 1, 2, \ldots, N \tag{1}$$

where $\underline{Z}_t' = (Z_{1,t}, Z_{2,t}, \ldots, Z_{p,t})$ is a vector of random variables, $\underline{a}_t' = (a_{1,t}, a_{2,t}, \ldots, a_{p,t})$ is a vector of random disturbances, and $\underline{\Phi}(B)$ and $\underline{\Theta}(B)$ are p x p matrices, assumed of full rank, whose elements are finite polynomials in the lag operator B, defined as $B^n Z_t = Z_{t-n}$. It is further assumed that $\underline{a}_t$ is $NID(0, \delta_{tt'}\underline{I})$, for all t and t', where $\delta_{tt'}$ is the Kronecker delta and $\underline{I}$ is an identity matrix of order N. Correlations among the disturbances can be modeled through $\underline{\Theta}(B)$.

Equation 1 can be used to analyze an economic system by partitioning $\underline{Z}_t$ into endogenous and exogenous variables. Suppose Equation 1 is partitioned as follows:

$$\begin{bmatrix} \underline{\phi}_{11}(B) & \underline{\phi}_{12}(B) \\ \underline{\phi}_{21}(B) & \underline{\phi}_{22}(B) \end{bmatrix} \begin{bmatrix} \underline{Y}_t \\ \underline{X}_t \end{bmatrix} = \begin{bmatrix} \underline{\theta}_{11}(B) & \underline{\theta}_{12}(B) \\ \underline{\theta}_{21}(B) & \underline{\theta}_{22}(B) \end{bmatrix} \begin{bmatrix} \underline{a}_{Y,t} \\ \underline{a}_{X,t} \end{bmatrix} \tag{2}$$

where $\underline{Y}_t$ is defined as a vector of endogenous variables, $\underline{X}_t$ is defined as a vector of exogenous variables, and $\underline{a}_{Y,t}$ and $\underline{a}_{X,t}$ are assumed independent. The assumption of exogeneity implies a number of restrictions on Equation 2. In particular, it implies that $\underline{\phi}_{21}(B) = \underline{0}$, $\underline{\theta}_{12}(B) = \underline{0}$, and $\underline{\theta}_{21}(B) = \underline{0}$. Thus, Equation 2 simplifies to yield

$$\underline{\phi}_{11}(B)\underline{Y}_t + \underline{\phi}_{12}(B)\underline{X}_t = \underline{\theta}_{11}(B)\underline{a}_{Y,t} \tag{3}$$

$$\underline{\phi}_{22}(B)\underline{X}_t = \underline{\theta}_{22}(B)\underline{a}_{X,t} \tag{4}$$

In this form it is clear that the exogenous variables are not influenced by the endogenous variables, a result required by definition. Equation 3 corresponds to the structural form of a linear, dynamic simultaneous-equation econometric model. Equation 4 describes the process by which the exogenous variables are generated. If $\underline{\phi}_{22}(B)$ and $\underline{\theta}_{22}(B)$ are restricted to be diagonal matrices, Equation 4 becomes a series of univariate-time-series models of the general autoregressive integrated moving-average form, one for each exogenous variable.

Consider the general linear model shown below:

$$Y_t = \beta_1 + \beta_2 X_{2,t} + \beta_3 X_{3,t} + \ldots + \beta_M X_{M,t} + a_t \tag{5}$$

The model in Equation 5 is similar to many models used in analyzing gasoline demand and is a special case of Equation 3. Equation 5 implies the following restrictions on Equation 3:

$$\underline{\phi}_{11}(B) = 1 \tag{6}$$

$$-\underline{\phi}_{12}(B) = (\beta_1, \beta_2, \ldots, \beta_M) \tag{7}$$

$$\underline{\theta}_{11}(B) = 1 \tag{8}$$

The appropriateness of the model can be examined by relaxing these restrictions (hypotheses) in such a way that they become testable.

An important, and frequently overlooked, restriction is represented by Equation 8. This restriction reflects the assumption that the disturbances of the model are uncorrelated. Pierce (8) and Granger and Newbold (9) have shown that inadequate testing of this restriction can lead to spurious regressions. It is doubtful that a priori information can be used to firmly establish this important restriction, and therefore it seems appropriate that it be tested in all applied econometric work with time-series data.

SPECIFICATION OF STRUCTURAL EQUATION

The basic specification of the structural equation for gasoline demand is similar to that for many models developed in the literature. Gasoline demand is assumed to be a function of real gasoline price, real disposable income, the fleet of gasoline-powered vehicles (automobiles and light trucks), and fleet fuel efficiency. A log-linear functional form was selected after a range of possible transformations had been considered, including the standard linear model (10, p. 87). Dummy variables were introduced to account for the effects that the 1973-1974 oil embargo and the 1979 fuel shortage had on gasoline demand (consumption). The general specification of the structural equation can be expressed as follows:

$$\begin{aligned} \ln GC_t = {} & \beta_1 + \beta_2 \ln GP_t + \beta_3 \ln DI_t + \beta_4 \ln VEH_t + \beta_5 \ln MPG_t \\ & + \beta_6 [\omega_1(B)/\delta_1(B)] EMB_t + \beta_7 [\omega_2(B)/\delta_2(B)] SHORT_t \\ & + \theta_{11}(B) a_t \end{aligned} \tag{9}$$

where

- GC_t = gasoline consumption in period t,
- GP_t = real gasoline price in period t,
- DI_t = real disposable income in period t,
- VEH_t = gasoline-powered vehicle fleet in period t,
- MPG_t = fleet fuel efficiency in period t,
- EMB_t = intervention for the 1973-1974 oil embargo (1 in 1973:3, 0 otherwise), and
- $SHORT_t$ = intervention for the 1979 fuel shortage (1 in 1979:2, 0 otherwise).

Equation 9 is obtained by placing the following restrictions on Equation 3:

$$\underline{\phi}_{11}(B) = 1$$

$$-\underline{\phi}_{12}(B) = \{\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6 [\omega_1(B)/\delta_1(B)], \beta_7 [\omega_2(B)/\delta_2(B)]\} \tag{10}$$

These restrictions are consistent with previous research and will be maintained throughout the analysis. The fact that all variables are expressed as natural logarithms allows the parameters of the equation to be interpreted as short-run elasticities. The operators $\omega_i(B)$ and $\delta_i(B)$, i = 1,2, are finite operators in the lag operator B and allow great flexibility in modeling the effects of the interventions (11). The specifications represented by $\omega_i(B)$, $\delta_i(B)$, and $\theta_{11}(B)$ will be determined during model identification and diagnostic checking.

The data used in this study consist of 86 quarterly observations that cover the period from 1960:1 through 1981:2. Data on real gasoline price and real disposable income were obtained from the state econometric model maintained by the Wisconsin Department of Revenue. Automobile registrations, light-truck registrations, and gasoline-consumption data were obtained from internal WisDOT sources. The gasoline-consumption series is defined in a manner similar to that for the series on the highway use of gasoline published by the Federal Highway Administration. The average fuel efficiency of the automobile fleet was used as a proxy for the fuel

Table 1. Autocorrelation functions of residual series obtained from preliminary, intermediate, and final stages in estimation of structural equation for gasoline demand.

	Residual from		
Lag	Equation 11	Equation 12	Equation 17
1	0.20	0.30[a]	−0.04
2	0.26[a]	0.15	0.07
3	−0.04	0.01	0.14
4	0.47[a]	−0.24[a]	−0.02
5	−0.12	0.04	0.09
6	0.02	0.01	−0.01
7	−0.20	0.06	0.11
8	0.30[a]	−0.01	0.02
9	−0.17	0.08	0.06
10	0.05	0.08	−0.01
11	−0.16	0.07	0.01
12	0.23	0.11	0.09
13	−0.28	−0.16	−0.06
14	−0.08	−0.14	−0.07
15	−0.29	−0.13	0.00
16	0.12	−0.18	−0.14

[a] Statistically significant at $\alpha = 0.05$.

efficiency of the gasoline-powered vehicle fleet. Data on fuel efficiency for the light-truck fleet were not available consistently. The fuel-efficiency series was adjusted to account for quarterly temperature variations in Wisconsin.

ESTIMATION OF STRUCTURAL EQUATION

The estimation of the structural equation for gasoline demand takes place in stages. In stage 1, Equation 9 is estimated with the restriction that $\theta_{11}(B) = 1$; i.e., the disturbances are assumed to be normally and independently distributed. The second stage involves an analysis of the autocorrelation function of the residuals and, if necessary, the identification of a model for the disturbances. In the third stage, the equation is reestimated by using the modifications identified in stage 2. As a check, the autocorrelation function is again examined. The model is accepted when further modifications are unnecessary.

As noted above, the first step in the analysis is to estimate Equation 9 with the restriction that $\theta_{11}(B) = 1$. The intervention terms are also ignored initially, so as to allow gasoline price per mile to explain as much of the variation in gasoline demand as possible. The results of the initial estimation phase are as follows (standard errors are given in parentheses):

$$\begin{aligned}\ln GC_t = &-5.60 - \underset{(0.05)}{0.72}\ln GP_t + \underset{(0.20)}{0.33}\ln DI_t + \underset{(0.21)}{0.97}\ln VEH_t \\ &+ \underset{(0.08)}{1.31}\ln MPG_t + e_t\end{aligned} \quad (11)$$

where

sum of squared errors (SSE) = 0.2030,
degrees of freedom (df) = 81, and
mean-squared error (MSE) = 0.0025.

Equation 11 explains 96.0 percent of the total sum of squares (total sum of squares about the mean = 5.065). The estimated coefficients are generally many times greater than their respective standard errors, which gives an impression of high statistical significance. However, an examination of the autocorrelation function of the residuals (Table 1) suggests that the residuals are seasonally nonstationary and autocorrelated, which makes the results of t-tests on the coefficients invalid. Seasonal nonstationarity is indicated by the fact that the residual autocorrelations fail to die out at integer multiples of the seasonal period (12, Chap. 9).

Seasonal nonstationarity can be addressed by taking a fourth-order difference of the data and reestimating the model. The results after reestimation are as follows:

$$\begin{aligned}(1 - B^4)\ln GC_t = &-\underset{(0.04)}{0.22}(1 - B^4)\ln GP_t + \underset{(0.13)}{0.44}(1 - B^4)\ln DI_t \\ &+ \underset{(0.15)}{0.44}(1 - B^4)\ln VEH_t - \underset{(0.22)}{0.60}(1 - B^4)\ln MPG_t + e_t\end{aligned} \quad (12)$$

where

SSE = 0.0608,
df = 78, and
MSE = 0.0008.

Use of a fourth-order difference reduced the SSE by 70 percent. Note that the values of the estimated coefficients have changed dramatically from those in Equation 11. These results confirm the importance of using both levels and differences of the data when modeling economic time series (9). However, a check of the autocorrelation function of the residuals from Equation 12 (see Table 1) indicates that the specification is still deficient. The residuals display significant autocorrelation at lags 1 and 4.

The following model was initially proposed for the disturbances:

$$e_t = \{(1 - \theta_4 B^4)/[(1 - \phi_1 B)(1 - B^4)]\} a_t \quad (13)$$

Equation 9 was reestimated with this disturbance structure, which produced the following result:

$$\begin{aligned}\ln GC_t = &-\underset{(0.06)}{0.24}\ln GP_t + \underset{(0.15)}{0.42}\ln DI_t + \underset{(0.17)}{0.59}\ln VEH_t - \underset{(0.26)}{0.69}\ln MPG_t \\ &+ \{(1 - \underset{(0.10)}{0.52}B^4)/[(1 - \underset{(0.11)}{0.44}B)(1 - B^4)]\} a_t\end{aligned} \quad (14)$$

where

SSE = 0.0452,
df = 75, and
MSE = 0.0006.

The autocorrelation function of the residuals from Equation 14 indicates that the model is adequate. Other disturbance structures were considered, but Equation 13 was shown to be most consistent with the data. The need for a seasonal difference was tested by replacing $(1 - B^4)$ with $(1 - \phi_4 B^4)$. The estimated value of ϕ_4 approached 1, which supported the use of a seasonal difference. A test of the restriction that $\theta_{11}(B) = 1$ was performed by using a likelihood-ratio procedure, and the restriction was rejected with $\alpha = 0.05$.

The residuals from Equation 14 were examined in an effort to determine plausible intervention structures. Initially, the following functional forms were proposed for the interventions:

$$\omega_1(B)/\delta_1(B) = \omega_1/(1 - \delta_1 B) \quad (15)$$

$$\omega_2(B)/\delta_2(B) = \omega_2 \quad (16)$$

The intervention structure given by Equation 15 allows an initial intervention effect (ω_1) to decay over time. If $\delta_1 = 0$, the effect disappears immediately, and if $\delta_1 = 1$, the effect is permanent. Further analysis indicated that Equations 15 and 16 were adequate representations of the effects caused by the interventions. By using these intervention structures, the final structural equation for gasoline demand becomes the following:

$$\begin{aligned}\ln GC_t = &-\underset{(0.06)}{0.22}\ln GP_t + \underset{(0.14)}{0.43}\ln DI_t + \underset{(0.15)}{0.59}\ln VEH_t - \underset{(0.26)}{0.92}\ln MPG_t \\ &- [\underset{(0.02)}{0.07}/(1 - \underset{(0.18)}{0.70}B)]\,EMB_t - \underset{(0.02)}{0.02}\,SHORT_t \\ &+ \{(1 - \underset{(0.10)}{0.47}B^4)/[(1 - \underset{(0.12)}{0.32}B)(1 - B^4)]\}\,a_t\end{aligned} \tag{17}$$

where

SSE = 0.0376,
df = 72, and
MSE = 0.0005.

Equation 17 explains 99.3 percent of the total sum of squares. The residuals (see Table 1) are uncorrelated and have a mean insignificantly different from zero. Skewness and kurtosis statistics indicate that the distribution of the residuals is consistent with an assumption of normality. Cross-correlations between the residuals and the stationary forms of the input series did not suggest the need for additional dynamic elements. Lagged values of ℓnGP and ℓnDI were introduced but yielded insignificant coefficients. The possibility that automobile and light-truck registrations should enter the equation separately was tested but yielded inconclusive results. There is no apparent need for further modification of Equation 17.

To this point, a direct-demand model has been used to specify the demand for gasoline. Indirect-demand models are also frequently used in analyzing gasoline demand, and closer examination of Equation 17 suggests that it may be consistent with an indirect modeling framework. This possibility can be tested by embedding an indirect model within Equation 9. An indirect model would take the following form:

$$\begin{aligned}\ln[(GC_t{*}MPG_t)/VEH_t] = &\beta_1 + \beta_2\ln(GP_t/MPG_t) + \beta_3\ln DI_t \\ &+ [\omega_1(B)/\delta_1(B)]\,EMB_t \\ &+ [\omega_2(B)/\delta_2(B)]\,SHORT_t + \theta_{11}(B)a_t\end{aligned} \tag{18}$$

Equation 18 implies the following restrictions on Equation 9:

$$\beta_4 = 1 \quad \beta_5 = -(\beta_2 + 1) \tag{19}$$

This relationship was estimated and yielded the following result:

$$\begin{aligned}\ln[(GC_t{*}MPG_t)/VEH_t] = &-\underset{(0.04)}{0.29}\ln(GP_t/MPG_t) + \underset{(0.05)}{0.10}\ln DI_t \\ &- [\underset{(0.02)}{0.07}/(1 - \underset{(0.15)}{0.74}B)]\,EMB_t - \underset{(0.02)}{0.02}\,SHORT_t \\ &+ \{(1 - \underset{(0.10)}{0.55}B^4)/[(1 - \underset{(0.11)}{0.37}B)(1 - B^4)]\}\,a_t\end{aligned} \tag{20}$$

where

SSE = 0.0400,
df = 74, and
MSE = 0.0005.

The intervention and disturbance structures are identical to those of Equation 17. A likelihood-ratio test of the restrictions given by Equation 19 indicates that the restrictions cannot be rejected at $\alpha = 0.5$. Equations 17 and 20 are therefore both consistent with the data. To a degree, preference for one representation over the other depends on one's point of view. A preference for Equation 20 can be based on the fact that it involves fewer parameters. Equation 17 is, however, less restrictive. At WisDOT, Equation 20 was selected based on the principle of parsimony (13, pp. 5-6).

EVALUATION OF STRUCTURAL EQUATION AND MODELING APPROACH

The results of this analysis indicate that gasoline demand is sensitive to changes in the size and fuel efficiency of the gasoline-powered vehicle fleet and is relatively insensitive to changes in real gasoline price and real disposable income. These results are in general agreement with other studies and indicate that increased fuel efficiency is perhaps the most effective means of reducing gasoline consumption.

The short-run elasticities estimated in this analysis are very sensitive to the specification of the model's disturbance structure. The elasticities obtained at different stages in the analysis are shown in Table 2. The most significant changes take place in the elasticities for fuel efficiency and real gasoline price. If the specification of Equation 11 had been accepted, the fuel-efficiency elasticity would have been estimated at 1.31 instead of -0.92 (or -0.71 if Equation 20 were used), and the real-gasoline-price elasticity would have been estimated at -0.72 instead of -0.22 (or -0.29). These results highlight the importance of diagnostic checking in the model-building process and demonstrate the effects that autocorrelated disturbances can have on estimated economic parameters. There is clearly a need to go beyond the standard first-order autoregressive model when alternative disturbance structures for econometric relationships are considered.

The similarities in the elasticities for Equations 12 and 17 (see Table 2) suggest that seasonal nonstationarity was a major contribution to the differences in elasticities noted above. Many studies of gasoline demand, or economic processes in general, deal with seasonality through the use of either dummy variables or sine/cosine functions. These approaches have important limitations. The use of seasonal dummy variables treats seasonality as a deterministic phenomenon, and this assumption is not likely to apply to economic processes. While sine/cosine functions can adapt to changing seasonal patterns, there is no assurance that they can represent seasonality in an economical manner. In contrast, Equations 17 and 20 contain a parsimonious specification of seasonality that adapts to changes in seasonal behavior [for further discussion of this topic, see paper by Cleveland and Tiao (14)]. This is an important property of disturbance structures from the autoregressive integrated moving-average class and can be particularly significant when a model is used for forecasting.

ANALYSIS OF FORECASTING PERFORMANCE

Forecast evaluation is an important part of any model-building exercise. In this section, Equations 11, 17, and 20 will be evaluated based on their root-mean-squared (RMS) forecast errors and their performance in terms of one-step-ahead forecasts. The forecasts analyzed here are conditional on the actual values of the exogenous variables during the period from 1981:3 through 1982:2. Box and Jenkins (12, Chap. 11) discuss the procedures used in producing forecasts by using economic models with generalized disturbance structures. The intervention effects estimated in Equation 17 have been added to Equation 11 so that the disturbance structures and accompanying economic parameter estimates are the only differences between these equations.

The gasoline-consumption forecasts produced by the alternative forms of the structural equation for

Table 2. Short-run elasticities obtained from preliminary, intermediate, and final stages in estimation of structural equation for gasoline demand.

	Elasticity from			
Variable	Equation 11	Equation 12	Equation 17	Equation 20
GP	-0.72	-0.22	-0.22	-0.29[a]
DI	0.33	0.44	0.43	0.10
VEH	0.97	0.44	0.59	1.00[b]
MPG	1.31	-0.60	-0.92	-0.71[b]

[a]Variable defined as real gasoline price per mile.
[b]Elasticities obtained by expanding all terms in model.

Table 3. Gasoline-consumption forecasts and RMS forecast errors for alternative forms of structural equation for gasoline demand.

	Actual Gasoline Consumption	Forecast Gasoline Consumption[a] (gal 000 000s)		
Period	(gal 000 000s)	Equation 11[b,c]	Equation 17[d]	Equation 20[e]
1981:3	541.4	637.3	544.8	550.9
1981:4	495.3	549.1	512.0	521.8
1982:1	416.0	528.7	452.6	459.2
1982:2	490.7	632.4	530.6	540.5
Total	1943.4	2347.5	2040.0	2072.4

[a]Forecast origin, 1981:2.
[b]Intervention effects from Equation 17 are added to Equation 11 in order to allow a fair comparison.
[c]RMS forecast error = 0.1994; actual and forecast consumption expressed as natural logs so that RMS forecast errors can be interpreted as approximate percentage errors.
[d]RMS forecast error = 0.0599.
[e]RMS forecast error = 0.0744.

Table 4. Gasoline-consumption forecasts for 1982:2 by using sequential forecast origins and alternative forms of structural equation for gasoline demand.

	Forecast Gasoline Consumption for 1982:2[a] (gal 000 000s)		
Forecast Origin	Equation 11[b]	Equation 17	Equation 20
1981:2	632.4	530.6	540.5
1981:3	632.4	530.5	540.0
1981:4	632.4	528.8	536.7
1982:1	632.4	516.5	521.3

[a]Actual gasoline consumption = 490.7.
[b]Intervention effects from Equation 17 are added to Equation 11 in order to provide a fair comparison.

gasoline demand are shown in Table 3. These forecasts indicate that Equations 17 and 20 are definitely superior to Equation 11. The RMS forecast error for Equation 11 is more than three times as large as that for Equation 17. This result demonstrates that the disturbances of a standard econometric model can contain significant amounts of information (in the form of autocorrelation) that can be used to develop models with improved forecasting performance. The forecasting results for Equations 17 and 20 indicate that Equation 17 outperforms its more restrictive competitor over the evaluation period used here. However, more experience is necessary before a decision can be made on which specificatión is superior. Examination of the squared forecast errors suggests that the performance of Equation 20 improved significantly in the first two quarters of 1982. In the end, it may not be possible to use forecast performance to discriminate between the equations. At this point, WisDOT is continuing to produce its forecasts by using Equation 20.

Table 4 demonstrates that updated forecasts of increasing quality can be obtained from the multiple-time-series specifications of gasoline demand. For 1982:2, the errors associated with forecasts produced by Equations 17 and 20 drop continuously as the forecast origin is moved forward. Updated forecasts for the other quarters (not shown) improved as well. Equation 11 cannot provide updated forecasts (without new forecasts of the exogenous variables) since it does not contain terms relating to the past history of gasoline consumption and previous forecasting errors.

WISDOT FORECASTING PROCESS

At WisDOT, the gasoline-demand model presented above (Equation 20) is one of a series of multiple-time-series models used in forecasting. Other models relate to automobile sales, truck sales, and the demand for special fuel. Automobile and truck sales forecasts are updated each quarter and are then used to produce revised forecasts of vehicle registrations and vehicle registration revenue. Gasoline and special fuel forecasts are updated and provide revised forecasts of motor fuel tax revenue. Forecasts for the exogenous variables driving these models are obtained from the state econometric model and from Data Resources, Inc.

The process of producing revised forecasts has received a positive response from WisDOT management. Previously, revised forecasts would be developed in a largely subjective manner. Some subjective elements still remain (and well they should), but tendencies to be either overly optimistic or pessimistic after a particularly good or bad quarter have been tempered by the rigor imposed by the models.

SUMMARY AND CONCLUSIONS

This paper has shown how a standard single-equation econometric model of gasoline demand can be embedded within a multiple-time-series framework. Use of this framework allowed the restrictions placed on the model to be tested for consistency with the data. The disturbances of the model were found to be seasonally nonstationary and autocorrelated at a number of lags. The values of the estimated short-run elasticities changed significantly when the disturbance component of the model was appropriately specified and estimated. The forecasts produced by the more general model were shown to be superior to those produced by the model that ignored the information contained in the disturbances.

The findings of this study underscore the need to test restrictions placed on econometric models. These tests are facilitated by the concept of nesting proposed models within a more general model structure and are discussed in detail by Harvey (13). In this study, specification tests that use nested models have lead to simplification of the original economic model and an adequate specification of its disturbance structure. The result is a parsimonious model, efficient parameter estimates, valid tests of those parameters, and improved forecasts.

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New Funding Sources for Public Transit: Who Pays?

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As financial crises have increasingly plagued transit systems, new and/or additional sources of funding have been sought. One issue that has not been well documented in this area is the question of who pays for each source. A number of potential household-based funding sources and their general impact on families at different income levels can be analyzed by using data published by the U.S. Bureau of Labor Statistics. Sixteen options including fares were examined and compared as to their relative regressivity (burdens). This was accomplished through a three-step process. First, relevant consumer expenditures by income levels were noted. Next, expenditures as a percentage of income were calculated. Finally, percentage expenditures by each income level relative to those of the highest income level were determined. The results can be used to compare the impact of one source versus another or to choose a source to minimize negative distributional impacts. Subject to certain qualifications, it was found that most household-based sources were regressive. The most regressive were household (head) tax, cigarette tax, and transit fares. Progressive alternatives include parking, income, and stock-transfer taxes. It is suggested that decreased federal funding will lead to the tapping of more regressive sources as well as to increasing reliance on business-based taxes, service cutbacks, and fare increases.

The financial problems of mass transit have become increasingly severe in recent years and are likely to get worse. Proposed budget cuts for the Urban Mass Transportation Administration (UMTA) could have significant consequences for transit systems. In particular, elimination of federal transit operating-assistance programs (Sections 5 and 18 of UMTA Act of 1964, as amended) has been anticipated. A recent survey by the American Public Transit Association (APTA) suggests that a majority of transit systems face reduced service, increased fares, and the need for new tax revenues and/or state and local assistance as a result (1).

Over the last dozen years, the financial condition of public transit has deteriorated markedly. In 1980, operating revenues of transit systems amounted to \$2.6 billion versus operating expenses of \$6.0-6.5 billion, a deficit of almost \$4 billion. This compares with an operating deficit of less than \$300 million in 1970 (operating revenue of \$1.7 billion, operating expenses of only \$2.0 billion) (2). In the past, this deficit has been largely closed by subsidies; the largest growth of these came from the federal government. With proposed reductions from this source, increased subsidies from other levels of government (state, regional, local), higher operating revenues (fares), or reduced operating costs (improved efficiency, reduced service) will be necessary.

There are a number of important issues that can be addressed in this area. For example, does transit offer benefit to nonusers to justify subsidies? Are the cities and suburbs being treated equally as far as transit benefits and costs are concerned? Are road versus transit funding being treated equitably? Should social considerations (e.g., taxes on cigarettes or alcohol) be involved? What funding sources are politically acceptable and substantial enough to offer short-term or long-term assistance? Should subsidies come from nontransportation users? Notably absent from most discussions of transit finance is the issue of how different income groups would be affected by the employment of different funding sources. While this may be due in part to the lower priority given this question, it may also be due to the lack of information available. It is the purpose of this paper to consider the general differences in who pays from various financing alternatives and to hold the profile of who benefits constant for simplicity.

In economic terms, the differential tax incidence of one source will be compared with that of another source. Differential tax incidence examines distributional changes by holding total revenue and expenditures constant while substituting one tax for another. Musgrave and Musgrave (3) suggest that this concept offers the best approach for tax policy analysis, since actual tax policy decisions usually involve issues such as comparing alternative ways of raising revenue.

Incidence refers to who (ultimately) bears the burden of a tax; that is, who pays. The initial distribution of burdens can differ from the final distribution if adjustments by consumers or firms are made in response to tax changes. This is called tax shifting. Unfortunately, there is serious disagreement on the final incidence of taxes that might be subject to significant tax shifting (e.g., property tax, corporate income tax, payroll tax). The final incidence of such business-based sources depends on changes in wages, prices, and profits as a result of the tax. Data on the shifting of tax burdens are scarce and there is little consensus on the result.

As a result, the funding sources analyzed in this paper are taxes levied on households, where the conventional wisdom [although it is not unanimous (4)] suggests that the initial and final distribution of burdens would be the same. This burden can be estimated by noting the expenditures or tax payments made by particular households. Most previous studies have concluded that the general category of sales and excise taxes tends to be regressive, whereas income taxes range from proportional to progressive depending on their structures (3,5).

RELATIVE INCIDENCE OF ALTERNATIVE HOUSEHOLD-BASED FUNDING SOURCES

Detailed spending patterns by U.S. families in different income brackets are required to examine the incidence of taxes levied on households. The only readily available and suitable data are provided by the Consumer Expenditure Survey (CES) of the Bureau of Labor Statistics (6), which is taken every 10-12 years, most recently during 1972-1973. This will allow comparison of the following funding alternatives on households: sales tax, motor fuel tax, cigarette tax, alcohol tax, automobile excise tax (new and/or used vehicles), parking and towing tax, (vacation) tolls, utility tax (electricity and/or natural gas), vehicle registration fee, income tax, title transfer fee, tickets and admissions tax, mortgage tax, a household (head) tax, and transit fares.

Calculating the relative incidence (burden) of each tax or fee requires a three-step process. First, expenditures on each item subject to tax or each tax amount must be noted by income level. A convenient breakdown available from the CES data is to arrange families by income decile from the 10 percent of families with the lowest income (decile 1) to the 10 percent of families with the highest income (decile 10). For four selected deciles (1, 4, 7, 10), gross expenditures are noted in Table 1. Each figure represents the average expenditure (in dollars) on an item by a family in a particular decile. The table notes, for example, that a decile-1 family spends $98 per year on gasoline, and this expenditure increases with income up to $561 for a decile-10 family.

The second step in this process is to calculate the percentage of income represented by the expenditure data in Table 1. The CES reports that the mean incomes of families in deciles 1, 4, 7, and 10 are $1559, $7063, $13 466, and $31 974, respectively. Table 2 displays the results, which indicate, for example, that spending on gasoline ranges from 6.3 percent of income in decile 1 to 1.8 percent of income in decile 10.

The final step is to look at the relative expenditure patterns by assigning an index number of 1 to the percentage spent on an item by the decile-10 family and scaling the spending by the other deciles accordingly. Since tax on the expenditure items would be proportional to spending, the relative incidence for either expenditures or taxes on expenditures by item will be the same. That is, comparing total expenditures on an item as a percentage of income for each population decile relative to that of decile 10 will yield the same relative pattern as the distribution of tax burdens applied to the item. The calculations are displayed in Table 3. This suggests, for example, that a decile-1 family pays a 3.5 times greater percentage of their income for gasoline (and thus gasoline taxes) compared with a decile-10 family.

DISCUSSION OF RESULTS

The funding sources considered in Table 3 can be categorized as progressive (taking an increasing percentage of income as income rises), regressive (taking a decreasing percentage of income as income rises), or proportional. Progressive sources have rising relative-incidence numbers as income increases. Parking and towing fees and state and local income taxes fit this description. Most of the other sources are regressive; they have relative-incidence values that fall as incomes rise. The degree of regressiveness differs significantly; a head (household) tax or a cigarette tax is seen to be extremely regressive; a new car excise or admissions tax is seen to be less regressive. Similar results occur if an S-index of progressivity is calculated (8).

Regressive taxes often carry a negative connotation. This notion stems from the ability-to-pay principle of taxation: those with greater ability should bear a proportionately larger share of the financing burden. This principle suggests that knowledge of the redistributive impacts of a tax could be used to select a particular funding source a priori or to mitigate any adverse consequences for the distribution of income a posteriori through ongoing governmental tax or transfer programs. A regressive tax would tend to place a heavier (percentage of income) burden on the poor and make the distribution of income less equal. In this sense, such a tax would violate the ability-to-pay principle. However, an alternative principle of taxation is to tax in proportion to benefits received. This principle excludes distributional considerations. Recently, there seems to be an implicit swing toward the benefit principle relative to federal transit funding.

In fact, "progressive" and "regressive" are technical terms with no value judgment attached. This classification, however, depends centrally on the initial distribution of income. For example, there is nothing inherently regressive about a sales tax. It is regressive because income is distributed unequally; the more unequal the distribution, the more regressive it becomes. Comparison of different taxes reflects the nature of these taxes in terms of the distribution of income of the society within which they are applied.

QUALIFICATIONS

Some qualifications need to be made to the above analysis. The data reflect actual spending patterns and thus incidence based on taxes and charges as they existed in 1972-1973. If the distribution of

Table 1. Yearly expenditures on taxable goods and services and other sources.

Item	Expenditure ($) by Decile			
	1	4	7	10
Taxable goods[a]	1407	3262	5139	8676
Taxable goods[b]	823	2201	3723	6847
Gasoline	98	270	449	561
Parking and towing	1	5	9	32
Tolls	0	2	4	8
Alcoholic beverages	33	79	127	252
Cigarettes	57	107	146	142
Gas and electric	135	222	320	432
Vehicle registration[c]	10	28	40	53
State and local income taxes	7	84	263	906
Title transfer fee[d]	1	3	4	5
New car purchases[e]	100	281	514	1005
Used car purchases[e]	73	191	338	407
Admissions and fees	11	26	54	116
New mortgage debt	180	410	1206	1462
Household tax[f]	18	18	18	18
Public transportation fares	33	56	42	88

Note: Data from Consumer Expenditure Survey (6).

[a] Goods subject to general sales tax, assuming that food purchased for home consumption and medicine and drugs are subject to sales tax. See paper by Rock (7) for more details.
[b] Assuming the items in footnote a are not subject to sales tax.
[c] Assuming a $25/vehicle fee.
[d] Based on the percentage of families purchasing a car and a fee of $10.
[e] Net outlay (excluding trade-in values).
[f] Assuming $18/family.

Table 2. Yearly expenditures as percentage of income.

Item	Expenditure (%) by Decile			
	1	4	7	10
Taxable goods[a]	90.3	46.2	38.2	27.1
Taxable goods[b]	52.8	31.2	27.6	21.4
Gasoline	6.3	3.8	3.3	1.8
Parking and towing	0.04	0.07	0.07	0.10
Tolls	0.02	0.03	0.03	0.03
Alcoholic beverages	2.1	1.1	0.9	0.8
Cigarettes	3.7	1.5	1.1	0.4
Gas and electric	8.7	3.1	2.4	1.4
Vehicle registration	0.6	0.4	0.3	0.2
State and local income taxes	0.5	1.2	2.0	2.9
Title transfer fee	0.07	0.04	0.03	0.02
New car purchases	6.4	4.0	3.8	3.1
Used car purchases	4.7	2.7	2.5	1.3
Admissions and fees	0.7	0.4	0.4	0.4
New mortgage debt	11.5	5.8	9.0	4.6
Household tax	1.2	0.3	0.1	0.1
Public transportation fares	2.1	0.8	0.3	0.3

Note: Data rounded off.
[a] See footnote a, Table 1. [b] See footnote b, Table 1.

these spending patterns has changed (and it certainly has), tax incidence could change. In a related manner, if the structure of taxes or charges changes, the results could be affected. For example, different fare structures (flat, zone, off-peak, weekend) would alter the transit expenditures of different income groups. Unfortunately, no updated CES has been scheduled. The implicit assumption was made that in response to tax changes, households would continue to buy taxable items or pay taxes in the same relative pattern as that which applied before. Any other assumption would vastly complicate empirical calculations. It is noted that if a tax used for transit funding is incremental to an existing source, the incidence would be essentially the same as the source to which it is attached.

Table 3. Relative incidence.

Item	Incidence (%) by Decile			
	1	4	7	10
Sales tax[a]	3.3	1.7	1.4	1.0
Sales tax[b]	2.5	1.5	1.3	1.0
Gasoline tax	3.5	2.1	1.8	1.0
Parking and towing fee	0.4	0.7	0.7	1.0
Tolls	1.0	1.2	1.1	1.0
Alcohol tax	2.7	1.4	1.2	1.0
Cigarette tax	8.3	3.4	2.5	1.0
Utility tax	6.4	2.3	1.8	1.0
Vehicle registration fee	4.0	2.4	1.9	1.0
State and local income tax	0.2	0.4	0.7	1.0
Title transfer fee	4.9	2.7	2.1	1.0
New car excise tax	2.0	1.3	1.2	1.0
Used car excise tax	3.7	2.1	2.0	1.0
Admissions tax	1.9	1.0	1.1	1.0
New mortgage tax	2.5	1.3	2.0	1.0
Household tax	20.5	4.5	2.4	1.0
Public transportation fares	8.2	3.0	1.2	1.0

Note: Based on unrounded data from Table 2.
[a] See footnote a, Table 1. [b] See footnote b, Table 1.

The use of a single year's income can be criticized as being unrepresentative of a longer-run view of income (9). Unfortunately, no data are readily available to correct this. Since national data were used, regional incidence could differ significantly from the reported figures due to local variations in tax rates, exceptions, expenditures, etc. The results should thus be viewed as a national aggregate. Some CES data are broken down by standard metropolitan statistical area and could give a limited picture of local incidence. In addition, data on alcohol expenditures, public transportation expenditures, and cigarette purchases suffered from serious underreporting (10). If the degree of underreporting was related to income, the reported figures could be biased. Due to the qualifications, it is difficult to ascertain the statistical significance of the results in Table 3. The results should be viewed as indications of regressivity or progressivity or the degree thereof rather than as statistically significant numbers.

Finally, a complete examination of equity would involve analysis of both who pays as well as who benefits. That is, the overall redistributive impact (or net fiscal incidence) of public transportation would consider the beneficiaries of the program as well as funding. The regressive nature of most funding sources could be countered by greater program expenditures (and benefits) that would accrue to lower-income families as major users. Social, legal, geographic, and fare-structure considerations similarly play an important role. The discussion above attempts to shed light on the who-pays groups by concentrating on differential tax incidence; it is recognized that this is only a portion of the total equity issue.

CONCLUSIONS AND IMPLICATIONS

The burden of increasing transit funding through a variety of sources has been examined by employing data provided by the U.S. Bureau of Labor Statistics. A number of potential subsidy sources as well as fares have been compared as to the income profiles of who pays from each potential source. The analysis suggests that choosing a new funding source or replacing one source with another has implications for the distribution of burdens. In addition, most sources are regressive; particular regressive sources include a household tax and the cigarette tax. Progressive alternatives include parking and income taxes. Of the sources studied, virtually all of them are less regressive than increasing fares. This is one factor to be aware of in the consideration of across-the-board fare changes.

In addition, choice of particular funding sources also affects the sectors of society who pay. A number of household-based alternatives (e.g., levies on motor vehicles and their operations) keep redistribution within the transportation sector, since automobile users are paying. Other sources involve nontransportation sectors of society; e.g., the general sales tax concerns all consumers. Higher fares and/or service cutbacks affect the user sector to the greatest extent.

Political realities play a large role in funding changes. Sources are typically sought that will maximize revenue and the likelihood of adoption and minimize controversy. Tax incidence frequently plays a minor role. The financial crises facing transit systems have led to consideration of a variety of funding options. For example, in the Chicago area, recent proposals included increased sales, liquor, tobacco, stock-transfer, property, income, and/or motor fuel taxes; a gross receipts tax on oil companies; a tax on professional services; and fare increases and service cutbacks. The size of the projected deficits has severely limited the number of options available. Many of the excise taxes on consumption would hit on such a small relative market that their total yield would be too small or the tax rate on these items would have to be prohibitively large. As can be deduced from Table 1, few consumer expenditures are large enough to raise reasonable sums through household-based taxes. The general sales tax; a specific excise tax on gasoline, utilities, motor vehicles, or new mortgages; and income taxes appear to be the only sources with adequate potential as revenue raisers. To avoid controversy, many of the politically favored sources are not household-levied taxes. For example, New York State recently approved a tax package that was heavily weighted in this direction. Included was a gross receipts tax on oil companies, a commercial transportation services tax, a capital-gains tax on business real property, and a change in the way oil company profits are computed for tax purposes. The avoidance of household-oriented taxes is probably due to a number of factors, which include the connotation surrounding the regressivity inherent in many of these taxes, the relatively small yield of most excise taxes, and the preferences for taxes that could be sold to the public as business taxes. Taxes levied initially on business have burdens that are well hidden from individuals. The incidence of such levies is also among the most unsettled and controversial aspects of public finance. Nevertheless, the burden of such taxes will be passed on to some group of individuals, either as consumers (through higher prices), firm owners or stockholders (through lower profits), or workers (through lower wages).

Recent trends in federal financing suggest that more of the burden of transit financing will be shifted to state and local responsibility, who find themselves fiscally weak. This will likely result in a larger burden on the transit user, through increased fares and decreased service levels, as well as nonusers through higher subsidies. Federal general appropriation funding tends to be progressive; it relies principally on the income tax. State and local funding, on the other hand, tends to be regressive; it relies more on sales and property taxes. User charges (fares, services), as concluded above, are extremely regressive. This suggests that increased state and local and user burdens would increase the inequality in the distribution of income.

The results presented above provide information relative to the burden of a number of household-based taxes that are frequently mentioned as subsidy sources. Further research into the incidence of business-based taxes would complement this analysis and improve the information relative to the who-pays question, which should play an important role in the decisionmaking concerning transit finance. An updating of expenditure patterns, when such data become available, would also be in order.

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Local Financing Opportunities for Urban Highway Transportation Improvements

STEVEN GAJ, ARTURO POLITANO, AND LEONARD GOLDBERG

Highways in the United States are at a turning point because of their condition and the cost to repair or replace them. Local public funds for highway construction and repair are not keeping pace with inflation due to reduced purchases of fuel and in some cases constraints on state and local funding, e.g., property tax limits. This paper addresses the funding dilemma by focusing on local financing, including sources of funding, the use of such funds, the range of opportunities for additional sources, and an evaluation of their merits. Based on a review of funding sources and their advantages and disadvantages, we conclude that while there are newly emerging sources such as toll financing, private financing, severance taxes, and others, the suitability of a specific source will necessarily vary. This is because each area has a unique financing philosophy and unique physical characteristics.

The U.S. Interstate highway system is deteriorating at a rate that requires reconstruction of 2000 miles of road per year (1). More than 4000 miles of the Interstate system and 13 percent of its bridges are beyond their designed life (2, pp. 2-3). In this decade and beyond, $47 billion will be needed to resurface, restore, rehabilitate, and reconstruct (the so-called 4R needs) the Interstate system. (This estimate by the Federal Highway Administration is based on combined estimates of 3R needs between 1980 and 1989, work shifted to 4R by the 1981 Federal-Aid Highway Act, and other needs indicated by state highway departments.) In addition, as much as $39 billion will be needed to complete the remaining 1289 miles of the system (3, Table 5).

The financial need is also felt by local areas. Older municipalities are experiencing a great need as well as growing municipalities. The problems of many cities or counties in financing their highway transportation system may be a result of tax structures that have not responded or cannot respond to capital, operating, or maintenance needs. Inflation is also a factor in the inability of local areas to keep pace with transportation needs. The general role of inflation is to reduce the purchasing power of expenditures.

HISTORICAL DEVELOPMENT: FINANCING HIGHWAY IMPROVEMENTS

In the recent history of highway construction, states have been relying heavily on fuel taxes, registration fees, and bonding. For example, in 1950, 74 percent of all revenue received by states came from user fees (46 percent from motor fuel taxes, 26 percent from motor vehicle taxes, and 2 percent from tolls) (4). In 1980, the same mix of financing sources constituted 52 percent of all state revenues (30 percent from fuel taxes, 17 percent from registration fees, and 5 percent from tolls) (5). In the same period, the amount of federal aid increased from 12 percent (1950) to 34 percent (1980). This reflects the increased importance placed on the Interstate system.

In contrast to the states, municipalities collect most of their local highway revenue from general fund appropriations and property taxes. In the 1970s the main sources of local revenue for municipal highways--the general fund appropriations and the property tax--have not changed. In both 1970 and 1979, nearly 70 percent of the revenue raised came from these two traditional sources. The remainder of the local revenue for both 1970 and 1979 came from miscellaneous receipts and bond proceeds.

In 1970, municipalities spent $3.4 billion on highway functions, or about 16 percent of the $20.8 billion spent by all levels of government. In 1979, they spent $7.7 billion on highway functions, or about 21 percent of the $37.5 billion spent by all levels of government. The maintenance function was the largest expenditure item; it made up a little less than 40 percent of the total municipal expenditure on highways in both 1970 and 1979. In municipal highway finance, the maintenance expenditure function increased 2 percent throughout the 1970s; in contrast, the percentage of money spent on capital outlay activities decreased 2 percent. On administration, the percentage remained constant; on debt service, it declined; and on law enforcement and safety, it increased.

In addition to municipalities, states also spent money on municipal highways. The main areas of expenditures were capital improvement and maintenance. The states spent most of this money on capital improvements as compared with maintenance functions. Thus the states' role in municipal highway finance is primarily in the area of capital improvements. The main role of the municipalities is primarily in the area of maintenance of local roads and streets.

Inflation in the 1970s eroded the spending dollar in the United States and in particular the expenditure on highways. In a comparison of the actual and constant dollar expenditures on highways in the areas of capital outlay and maintenance, actual spending on capital outlay increased through the decade (from $4 billion in 1970 to $6.5 billion in 1979); real spending in constant 1977 dollars declined significantly (from $7.5 billion to $4.5 billion). In the maintenance areas, actual spending doubled in the 1970s from $1.5 to $3.5 billion, whereas real spending in constant 1977 dollars remained relatively constant--about $3.0 billion. Today, public funds for highway construction and repair are also not keeping pace with inflation and reduced fuel purchases. Alternative funding mechanisms for local areas are needed.

LOCAL FUNDING TECHNIQUES

Two general categories of opportunities for local financing of highway projects are considered: user and nonuser mechanisms. As the name of the category implies, the user category includes mechanisms that are directly associated with the use of the highway system. The underlying principle here is that the users bear the main financing responsibility for highway improvements. In contrast, the financing responsibility for nonuser mechanisms is shared by the population at large. User mechanisms include motor fuel tax, motor vehicle fees and taxes, parking taxes, and toll financing. Nonuser mechanisms include property taxes, sales taxes, local payroll or income taxes, bonds, private funding, special-benefit assessments, value capture taxes, and severance taxes.

User Pay Mechanisms

Motor Fuel Tax

In 1981, state rates ranged from 5 to 14 cents/gal

(6). During the last couple of years, many states increased their tax rates and increased the amount they distribute to their local areas. Some areas also have an additional motor fuel tax added to the state tax. For example, a recent California law allows counties to piggyback a 5-cent local tax on the state gasoline tax for highway and transit purposes.

Some states have variable motor fuel taxes, which reduce the impact of inflation. Some states have a percentage tax, such as that in Northern Virginia. With a 2 percent tax increase on the retail sales value of a gallon of gas for jurisdictions within the Northern Virginia Transportation District, the increased tax is expected to generate $9.5 million. This tax requires state legislative approval, however.

Motor Vehicle Fees and Taxes

Motor vehicle fees and taxes can take many forms. Fees include registration, driver's license, certification of title, etc. Taxes include sales taxes on motor vehicle parts, gross receipts taxes, and ton-mile and passenger-mile taxes. Iowa places a 3 percent sales tax on new and used motor vehicles (7).

Tolls

In the Tidewater area of Virginia, tolls had been paid since the 17th century for crossing the Hampton Roads Channel (8). Today, many areas are considering tolls as a source of additional revenue. One such city is Charleston, South Carolina (9). Charleston is in need of major improvements on bridges leading into the city and possibly several new facilities that will provide access to outlying areas. The 1916 Federal-Aid Highway Act stipulated that all roads be free of tolls. In 1956, with the commencement of the Interstate system, Congress adjusted its long-standing policy and allowed federal-aid funds to be spent on approaches to toll roads that were designated part of the Interstate system. However, tolls were to be eliminated as soon as the capital cost was repaid and the debt retired. Congress authorizes payback of the federal funds used for facility construction in those exceptional cases when Congress has permitted tolls on federal-aid highways.

Nonuser Pay Mechanisms

Property Tax

Property taxes are of major significance to local governments. In 1976, local governments received 82 percent of their highway-related tax revenue from this source.

In general, a property tax can be placed on all tangible objects from homes to motor vehicles. Property taxes are based on the value of the object. They can be levied by the state, the local area, or a special authority. In many states, the revenue received from the property tax on motor vehicles is used for highways. The additional revenue can easily be calculated by reviewing motor vehicle registrations and the proposed tax rate. The rate can be adjusted until the desired level is reached. Recent referendums have placed limits on the property tax rate. Proposition 13 in California and 2 1/2 in Massachusetts are two examples.

Sales Tax

The majority of states (46) levy a retail sales tax and/or give the authority to levy such a tax. After the property tax, the sales tax has become the largest source of local revenue. Most statewide rates fall between 2 and 6 percent. The items on which a sales tax is paid vary among states. For example, in some states a sales tax must be paid on food purchases and in others it does not.

Twenty-four states allow local governments to levy a local sales tax that can be combined with the state rate and collected by the state governments for local use (10). For example, New York has a state rate of 4 percent, and New York City also has a rate of 4 percent; thus in New York City an 8 percent sales tax is collected. Many areas subsidize public transit through a regional sales tax. In 1982, Atlanta estimated their sales tax revenue to be $110 million.

Bond Financing

Bonds are an excellent source of revenue for a local area. They must be backed by a reliable revenue source to be sellable at favorable interest rates. This may be accomplished in several ways: (a) pledge revenue of an earmarked tax, (b) pledge surplus revenues of other public revenues, and (c) pledge the good faith of a state or local government. One example of where bond financing has worked well is in the Houston urbanized area. Between August 1978 and September 1979, Harris County raised $338 million, of which $175 million was earmarked for major thoroughfare improvements, and the City of Houston raised $395 million, of which $185 million was allocated for street improvements (11).

Bonds are not so attractive today as they were in the past. To spur private saving and investment, recent tax-law changes have provided special tax-exempt investment schemes such as all-savers certificates and have broadened the scope of individual retirement accounts. This has reduced the attractiveness of long-term tax-exempt municipal bonds. To reflect changing times, short-term borrowing instruments have been developed, such as unsecured tax-exempt commercial paper (12).

Impact Taxes or Fees

Impact taxes and fees are mechanisms by which a private developer pays a local jurisdiction for the abatement of effects caused by a proposed residential, commercial, or industrial development on the jurisdiction's services. Most often, the impetus for the tax or fee can include local zoning ordinances or proffer requirements to obtain a planning board's approval or specific site-plan and specification approvals.

These mechanisms are quite common to development and construction of residential, industrial, and commercial complexes. For an example, we draw on a commercial project, the Hickory Point Mall in the Village of Forsyth, Illinois. In order to facilitate the free flow of traffic and to ensure safety to the motoring public when the mall is in operation, the developer paid the State of Illinois $1 331 300 to reimburse the state for widening a 0.75-mile segment of US-51 and providing four through traffic lanes, auxillary right-turn lanes, a 36-ft median with left-turn lanes, entrances to the shopping center, storm sewers, and traffic signal installation. As a consequence, the Village of Forsyth approved the developer's plans.

Severance Tax

A severance tax is a tax placed on a commodity that leaves the indigenous geographical area. Several states have severance taxes. Arkansas places a sev-

Table 1. Comparison of revenue sources.

Revenue Source	Issue: Generate Revenue?	Sensitive to Inflation?	Expensive to Administer?	Independent of Gasoline Price?	Independent of Market?	Acceptable to Public?	Equitable?
User mechanism							
Motor fuel tax	+	0	-	-	+	0	+
Motor vehicle fee and tax	0	-	-	0	+	0	+
Toll	+	-	+	-	0	+	+
Nonuser mechanism							
Property tax	+	+	0	+	-	-	-
Sales tax	+	+	0	+	-	-	-
Bond financing	+	+	0	+	0	+	+
Impact tax or fee	0	+	0	+	0	+	+
Severance tax	0	+	0	+	-	+	+

erance tax on natural resources and turns back 12.5 percent of the gross receipts to the county's highway fund. Kentucky's coal severance tax goes to the state road fund, whereas its mineral severance tax goes to local governments' economic assistance funds. New Mexico, Oklahoma, and Wyoming also have similar taxes (7).

Analysis of Mechanisms

Several criteria can be used as the means of appraising the many local opportunities for raising revenue for highway projects. These include

1. Ability to generate revenue,
2. Sensitivity to inflation,
3. Ease and cost of administration,
4. Independence from gasoline price fluctuations,
5. Minimum interference with efficient markets,
6. Public acceptance, and
7. Equity.

A comparison of the revenue sources reviewed in the last section is shown in Table 1. The revenue sources are divided into two categories--user-derived and non-user-derived sources. Each source is then evaluated subjectively according to each criterion: a plus sign indicates that the source has a positive effect on the criteria, a minus sign indicates a negative effect, and a zero indicates either that there is a balance of effects or that the effect is unknown.

From Table 1, it can be seen why user mechanisms have been attractive: They generate revenue well, have generally low administrative cost, are generally independent of the market, have been accepted by the public, and are equitable. They are generally equitable because the users of the highway system are tapped for money to build or repair the system. The two greatest disadvantages of the user mechanisms are that they are not sensitive to inflation and they are not independent of changes in consumption.

In contrast, it can be seen that nonuser mechanisms as a group may generally complement existing sources by generating more money, as bonding has for Houston, Texas. They are sensitive to inflation, generally independent of gasoline price increases, and administratively inexpensive to implement. There are, however, clear disadvantages. They generally interfere with the market, are not readily accepted by the public, and are inequitable.

Perhaps one of the key criteria that local areas may have to consider is whether the specific mechanism is acceptable to the public. A recent survey sponsored by the Advisory Commission on Intergovernmental Relations (13) can provide some insight. In response to a question on the least fair tax, close to a third of the respondents cited the federal income tax or the local property tax. This response is repeated in another question, which asks for the best way to raise revenue. In this question, respondents named the following in order of preference: charges for specific services, local sales taxes, local income taxes, and local property taxes.

CONCLUSION

A number of local opportunities for generating revenue have been suggested in this paper; they include user and nonuser mechanisms. User mechanisms have been generally found to be more acceptable to the public and more equitable. However, user mechanisms may have mixed blessings, since they have a limited ability to keep pace with inflation or fuel price increases and to maintain a steady revenue level in times of reduced motor fuel consumption. In contrast, nonuser mechanisms generally have the reverse effect.

The choice of specific funding mechanisms must reflect an urban area's unique philosophy and goals regarding the highway system and who should pay. The magnitude of financial need and the existence of natural resources will necessarily influence their decision. For example, the magnitude of financial need may be large enough to require a package of mechanisms, both user and nonuser.

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Abridgment

Private Funds for Highway Improvements

DAVID W. SCHOPPERT AND WILLIAM S. HERALD

Public works finance has become a topic of increasing concern to officials at all levels of government. Fiscal restraint has become a national objective that has severely affected the ability of government to finance improvements from tax revenues. A review of the expenditures for highway projects indicates that increases in construction and maintenance costs have substantially diminished the purchasing power of current funding levels. There is general agreement that current funds from traditional sources are much less than the amount needed to even preserve existing performance levels in the future. One potential source of new or additional funds for highway improvements is the private sector. A number of techniques have been employed, primarily by local governments, to obtain private financial assistance for highway projects. These techniques and their success in securing private funds have varied widely. Several approaches are linked to land use regulation and the approval process for new development. Other mechanisms are based on innovative tax proposals. A brief description is provided of a number of examples of the use of private funds for highway improvements. A preliminary evaluation of techniques to obtain private funds indicates that incentive zoning, special-benefit assessments, and dedicated property taxes may offer the greatest potential for widespread application. Obstacles to the wider use of private funds may include legal restrictions and the financial burden imposed on developers. Several conclusions on the current status of private funding of highway improvements are offered. Although it is clear that a significant volume of private participation already occurs, there is little or no attempt to account for it. Thus, it is difficult to estimate the contribution that private funding can make to highway finance. The strength of the development market is a key factor in the private sector's willingness to pay for public works improvements. More research is needed to identify the opportunities for increased use of private funding sources in the future.

In the past decade, highway finance in the United States was severely buffeted by the twin forces of inflation and the general movement to stabilize or reduce taxes of all kinds. Although revenues for highways increased during the period, their growth rate did not begin to match the rapid increase in construction costs, which substantially outpaced the consumer price index.

As suggested in the following quotation, taken from a recent study of public works needs for the 1980s (1), the response to rising costs and lagging revenues has been to find new ways to finance highway improvements: "The deteriorated condition of basic facilities that underpin the economy will prove a critical bottleneck to national economic renewal during this decade unless we can find new ways to finance public works." For some highway officials, particularly in local government, a new way to finance improvements has been the use of private funds. Working primarily through discretionary powers in local land use regulations, transportation officials in many areas have negotiated for improvements to public highways at the initial expense of real estate developers.

In many cases, the use of these techniques has been successful in significantly reducing the amount of funding required for roadway improvements. Because of this success, there is an emerging interest in expanding the application of the concept.

The increased use of private funds for highway improvements will be accomplished by extending involvement to more local and state governments and more effective use of these mechanisms by communities in which they are already in use. To achieve this extension and increased effectiveness, better information on these mechanisms is required. There is a particular need to document and consolidate existing experience in order to illustrate the full range of techniques available and highlight methods to overcome obstacles to their use.

This paper takes the first steps toward meeting this need. The purpose is to identify some of the innovative mechanisms used to negotiate the commitment of private funds for highway improvements, describe some ways in which they have been applied, and assess their potential for widespread application in the future.

NEED FOR ADDITIONAL FUNDING

There is substantial evidence that the United States is not investing enough money in its streets and highways. For that matter, we are not investing enough in any public facilities. In the introduction to America in Ruins (1), the situation is described in these words:

> America's public facilities are wearing out faster than they are being replaced. Under the exigencies of tight budgets and inflation, the maintenance of public facilities essential to national economic renewal has been deferred. Replacement of obsolescent public works has been postponed. New construction has been cancelled.... The costs of rehabilitation and new construction necessary to maintain existing levels of service on non-urban highways will exceed $700 billion during the 1980's.

Figure 1. Price trends for federal-aid highway construction.

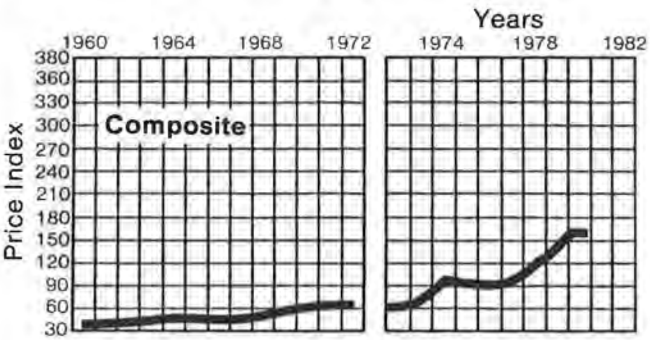
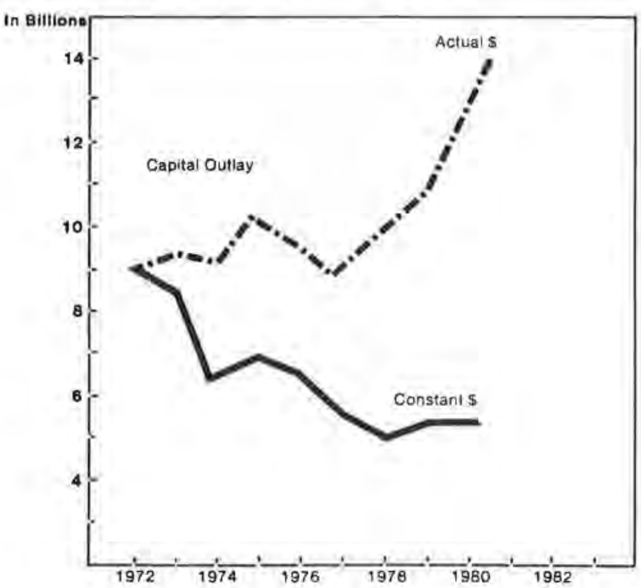


Table 1. Capital outlays for state-administered highways.

Year	Capital Outlay ($)	Construction Cost Index (1977 = 100)	Outlay ($ 1972)
1972	8 981 484	62	8 981 484
1973	9 383 859	70	8 311 174
1974	9 390 755	92	6 328 552
1975	10 168 550	91	6 928 023
1976	9 676 656	91	6 592 885
1977	8 882 863	100	5 507 375
1978	10 015 634	120	5 174 744
1979	11 798 070	138	5 300 582
1980	14 013 201	160	5 430 115
Total	92 311 073		58 554 934
Eight-year total	83 329 589		49 573 450

Figure 2. Disbursements for state-administered highways.



The highway finance problem is in large part the result of two trends of relatively recent origin: increasing costs and declining revenues.

Figure 1 shows the price trend for federal-aid highway construction from 1960 through 1980. Note that prices rose very gradually until about 1973, when they began to rise sharply. Except for a leveling off in 1975 and 1976, prices of federal-aid highway construction have continued to climb; in

Figure 3. Growth of highway construction, consumer prices, and highway revenues, 1970-1979.

1980 prices were roughly 2.6 times those in 1972. Table 1 shows what this has done to the purchasing power of capital outlays in terms of 1972 dollars. Capital outlays have grown very little since 1972; they averaged about $9-$10 billion until 1979 and 1980, when they increased to about $12 billion and then $14 billion. When those outlays are converted to 1972 dollars, it can be seen that they have not bought much. During the eight years since 1972, outlays of $83 billion have purchased only $50 billion worth of construction in 1972 terms. Clearly, increasing costs have had a dramatic impact on the highway system; a shortfall in investment value of about $30 to $35 billion has been created in the past eight years. The relationship between actual outlay and constant-dollar outlay is shown in Figure 2.

The other half of the picture is revenue. States derive most of their funds for highways from motor fuel taxes, although they use several other sources as well. For a variety of reasons (one is that most gasoline taxes are fixed rates per gallon; a second is the reduced rate of growth in vehicle miles of travel; and a third is the replacement of many vehicles with more fuel-efficient vehicles), revenue has not kept pace with costs. The Government Accounting Office (GAO) estimates that construction costs rose 145 percent from 1970 to 1979, whereas revenues rose only 60 percent. At the same time the cost of maintenance, administration, and debt service (for new bonds) also increased. Figure 3 shows cost, price, and revenue trends developed by GAO in their report to Congress on the Federal Highway Program (2).

These data on costs and revenues demonstrate that the funding resources for highways are insufficient to maintain the performance of the nation's highway system even at the level that prevailed in the mid- to late 1970s. Estimates of dollar needs for highways vary widely depending on the analysts' approach and whether the estimate includes all highways or only the federal-aid system. It is enough to realize, however, that funds needed for the highway system of the future (including resurfacing, reconstruction, maintenance, and new construction) far exceed the traditional available sources of revenue.

The clear choice, then, is either to accept the accelerating deterioration of the highway system or to find new ways to obtain needed highway improvements. Among the latter is the use of nongovernment funds.

REVIEW OF CURRENT PRACTICE

Techniques to obtain private funds for highway improvements have been employed most often by local governments. Although there are notable examples of private participation with state government projects, such as the Hackensack Meadowlands development described in the examples below, the major activity in this area has been a function of the power of local government to regulate the use of land.

Land use regulations vary widely across the country and reflect state-to-state differences in enabling legislation and regulatory approach. In general, however, legal systems for controlling the use of land employ the basic concepts of zoning and subdivision ordinances. These tools, when used in conjunction with the officially adopted local comprehensive plan, form the basis for public control and guidance of the development process.

It is not surprising, then, that the primary legal tools of zoning, subdivision, and site-plan approval have also formed the basis for obtaining private funds for highway improvements. Indeed, it is possible to view the development of the private funding for highway improvements as an extension of the normal application of the subdivision ordinance.

These two elements, the developer's responsibility for infrastructure and the process of bargaining with local officials for approval, have gradually evolved into a variety of systems designed to secure developer provision of off-site highway improvements. These improvements become a de facto condition for approval of the subdivision of formerly rural land for commercial use. It is these major off-site improvements that are of special interest in this study.

In addition to subdivision approval, such strategies for obtaining private involvement now also employ approaches based on an adequate public facilities ordinance and the zoning ordinance. The need for flexibility to respond to the current development market has led to the invention of a number of innovative zoning techniques such as floating zones, impact zoning, performance zoning, and incentive zoning. Although there are important distinctions among these techniques, they all reflect the need for flexibility in application, consider the impacts of a development on the adjacent area, and incorporate some degree of negotiation between developer and government to produce an agreement.

A preliminary survey of municipal transportation planners indicated that one mechanism for obtaining private funds for highway improvements is the project-approval process. This decision power is in the hands of local government when a developer requires a change in zoning, a special permit, or approval of a subdivision. Official approval of that request is made conditional on the developer's provision of necessary improvements and amenities. For example, in Fairfax County, Virginia, any request for rezoning or subdivision approval is to include "proffers" from the developer, which list the amenities and improvements (ranging from highway construction to children's play areas) that will be made if the approval is granted.

In approaching this effort, we must recognize that there are a variety of techniques that can be used to obtain private participation in funding highway improvements. Land use regulation is one category in a spectrum of financing techniques that also includes taxation, special assessments, and the use of public land for sale, lease, or development. A preliminary list of the available techniques would include the following:

1. Land use regulation
   a. Dedications and exactions: developers provide land and/or highway improvements (dedication) or cash (exactions) as a condition for zoning-subdivision or building-permit approvals
   b. Incentive zoning: incentives for increased floor space in exchange for developments that include desired street improvements
   c. Official maps: typically official maps preclude building permits for land within the proposed rights-of-way of major roads and streets
2. Taxes, special assessments, and service charges
   a. Tax-increment financing: all or part of the property tax increased beyond a frozen base in a specified district is reserved for street and highway improvements; other infrastructure investments may be included in addition to streets and highways
   b. Special benefit district: government levies a special charge on property within a specified district; widely used in residential areas by cities since the 1800s
   c. Service charges: a service charge is a special fee for site-plan approval; can be a one-time or continuous charge to recover costs of roads and streets
3. Public land acquisition
   a. Lease or sell air rights: the lease or sale of rights to build above the right-of-way (could also be below elevated freeways)
   b. Lease or sale of excess property: rights-of-way in excess of need are acquired prior to construction and then sold or leased to developers
   c. Joint development: highway agency contributes land and/or air rights or extends loans or loan guarantees to developers in exchange for an equity position in the development

Obviously, these techniques cover a wide range and are directed to more than just private funding sources. Some mechanisms, such as land use regulations, permit in-kind contributions of land or actual improvements rather than cash. Other techniques, such as tax-increment financing, are really using public tax receipts collected in a somewhat innovative fashion. To the extent that these new revenues would not be available without the specific need for highway improvement, however, it is possible to view them as private funds. The lease or sale of air rights or excess property can provide funds from private sources but only in exchange for assets of equal value.

Toll-financing, a prominent form of the use of private funds for highway improvements through the sale of revenue bonds, is not included in this list of techniques. This mechanism is already familiar to highway planners and constitutes a special case substantially different from the negotiated agreements for private funding that are of principal interest in this paper.

EXAMPLES OF DEVELOPER PARTICIPATION

To illustrate the diversity of the possible approaches, we have described several examples drawn from our experience with developer participation in financing highway improvements, which comes from serving both private and public clients throughout the United States and in several foreign countries. The following examples of a range of recent projects illustrate both the advantages and some disadvantages of this approach.

Transportation Improvement District--Denver, Colorado

Near Denver, Colorado, local governments and private business interests are working with examples of two techniques to generate continuing funding for transportation improvements in a very active development market. The Denver Technological Center (DTC) now has 1.8 million ft^2 of floor space and about 7000 employees. The local government, Greenwood Village, levies a head tax of $1.00 per employee per month on the employers located in the center. The funds generated by the tax are used by the village to provide various infrastructure improvements, which include highway facilities.

The area immediately surrounding the center has about 2.0 million ft^2 of commercial floor space that lies outside Greenwood Village. The developers who are active in DTC and its surroundings were instrumental in getting Arapahoe County to create a transportation improvement district for the entire area. The district prepared a transportation improvement program, which is keyed directly to the pace of proposed development. Improvements are financed by special assessments on the property within the district. Current projects include construction of an overpass on Yosemite Road over Interstate 25, construction of the Dry Creek Road interchange, and widening Belleview Avenue. The Colorado Highway Department has designed and is supervising construction of the improvements, for which the total cost is estimated to be $17.8 million.

It is significant that the improvement district was initiated by the developers as a mechanism to assure an orderly program for equitably allocating the costs. Especially noteworthy is the fact that the approach secures private funds but eliminates the continuing need for negotiation between developers and government. Therefore, a coordinated system of improvements can be implemented on a timely basis without the risk of delays or disagreements over each developer's financial responsibility. The employee head tax provides a stable and continuing source of funds that can be applied to problems with the highest priority for resolution.

State Control of New Development--Hackensack, New Jersey

For decades, the 21 000 acres of the Hackensack Meadowlands was viewed as a major opportunity for development in the New York metropolitan area. In order to assure that this valuable resource was used wisely, the State of New Jersey created the Hackensack Meadowlands Development Commission, which assumed all control of land use in the area, formerly administered by 14 different municipalities. The commission has actively pursued a policy of requiring developers to provide all types of transportation infrastructure. For example, Hartz Industrial Park was required to build and maintain a six-lane divided arterial with an actuated signal system at every intersection. Also required was a commuter rail station, privately funded bus service, an intermodal transportation center, an automated peoplemover, and a complete access-road network. Many of these facilities were constructed, operated, and maintained at private expense.

Local Transportation Trust Fund--Roseville, California

To pay for needed highway improvements, the City of Roseville has a policy of exacting 2 percent of the construction cost of new developments. It is not known whether this policy has been tested in the courts, but it accords with proposals for growth management that have been put forward in California and other high-growth areas.

Public Corporation and Private Funds--New York City

The Lower Manhattan Plan called for development on fill between the bulkhead and pierhead lines in the Hudson River. As part of the development, the old West Side Highway was to be demolished and replaced with a partly depressed highway connecting to Battery Park Tunnel. This development was undertaken by the Urban Development Corporation (UDC), which is a public corporation financed by the sale of revenue bonds. UDC participated in financing the roadway improvements as well as the placement of the landfill and the construction of the development. Although UDC is not, strictly speaking, a private developer, it does develop housing and commercial property to achieve a public purpose and frequently finances infrastructure improvements to its sites.

OBSTACLES TO INCREASED PRIVATE FINANCING

One need is to examine the legal and practical obstacles to the the use of private funds for highway improvements. At this point, it is useful to take note of what these obstacles are in order to clearly focus our research priorities on the assessment of their impact and on methods to overcome them.

A preliminary list of problems in the use of private funds would include these concerns:

1. Administrative and institutional constraints,
2. Financial feasibility,
3. Context variables,
4. Transportation system development,
5. Cost allocation, and
6. Accounting and documentation.

As noted in the examples described above, the use of private funds for highway improvements requires extensive administrative effort and institutional coordination. Although there are legal limits on the extent that developers can be encouraged to finance or provide highway facilities, these limits have not been clearly defined and are not widely known.

Financial feasibility may pose a major practical obstacle to the use of private funds for highway improvements. The private sector will provide such financing only to the extent that it is advantageous to do so. If development revenues are not sufficient to provide the improvements sought by government, then there will be no addition to the municipal tax base and no improvements to local roadways.

Many developers already bear large financial burdens for the provision of infrastructure. In a typical single-family housing development, site-preparation costs range from $7000 to $12 000 per lot. Site preparation for townhouse lots ranges from $4000 to $7000. These costs include lot grading, clearing, sewer, water, and utility provision, but streets are an important consideration. For a single-family lot in a new subdivision, street costs will range from $3000 to $5000 per lot. In addition, residential and commercial developers often contribute substantial amounts of right-of-way and construction to arterial roads and streets. Such contributions have an impact on the cost of housing or office space for the consumer. These markets are currently in recession in many parts of the country and so it can be questioned whether they can support an additional burden.

Most of the techniques in current use are applied in urban areas, especially fast-growing suburban jurisdictions. Rural areas may require special adaptation of these mechanisms before they can be applied. Similarly, the success of these techniques is closely related to the overall development market. Cities and states in growth areas like the South and West may have more success in obtaining private funds than stable or declining cities where the real estate development market is weaker. Local attitudes may also be significant; they may reflect a basic pro-growth or anti-government-regulation point of view that would influence local or state policy.

Another problem in the use of private funds for highway improvement is its impact on the orderly development of the transportation system. Reliance on developers to provide highway facilities may result in a jumbled pattern of piecemeal improvements. Frequently, private investment in highway improvements is poorly utilized because only short sections are improved or current traffic volumes do not warrant facilities required to serve an ultimate future development density.

PRELIMINARY EVALUATION OF TECHNIQUES

Recent research into innovative financing mechanisms for public transit may be transferable in part to highway improvements. Because of the lack of a stable funding source such as the Highway Trust Fund, public transit planners have been very active in exploring the potential for new, nongovernmental sources of funds for capital and operating expenditures. Although there are important differences between the development of highway and transit improvements, they share some common elements. Figure 4 presents a summary evaluation matrix of the techniques listed earlier, adapted from a study of transit financing (3).

The evaluation indicates that some types of mechanisms have considerably more promise than others, although none was ranked higher than moderate for overall potential. The dedicated property tax and the special assessment, similar to the Denver example described earlier, show relatively high value in terms of financing potential, institutional feasibility, and transferability. Other highly rated techniques include incentive zoning and the sale or lease of air rights. Techniques that show promise despite problems with institutional feasibility include tax-increment financing and service charges.

CONCLUSIONS

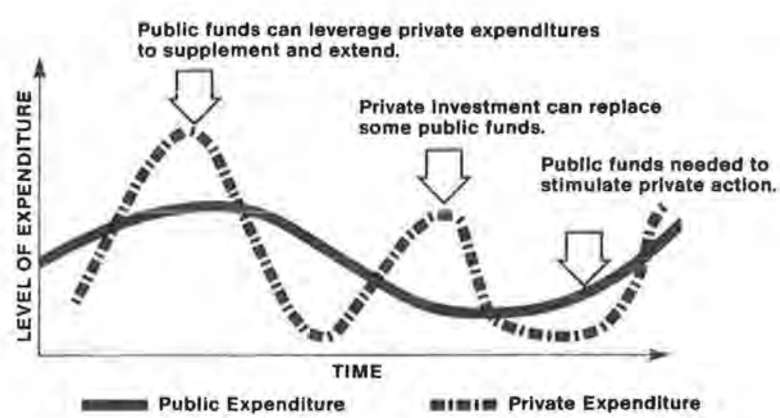
Available data on highway finance demonstrate that current levels of public funding are not adequate. Current expenditures are not sufficient to maintain even recent levels of highway performance on the

Figure 4. Preliminary evaluation of private funding techniques.

	Financing Potential	Institutional Feasibility	Scope for Use in U.S. Cities	Overall Promise for Highway Finance
Incentive Zoning	◑	◑	◑	◑
Special District Zoning	◑	○	○	○
Dedications and Exactions	○	◑	○	○
Official Map	○	◑	○	○
Dedicated Property Tax	●	●	◑	◑
Tax Increment Financing	●	○	◑	◑
Special Benefit Assessment	◑	◑	◑	◑
Service Charges	◑	○	◑	◑
Lease or Sell Air Rights	◑	◑	◑	◑
Lease or Sell Supplemental Property	◑	○	○	○
Develop Air Rights/Supplemental Property	◑	○	○	○
Participate in Property Development	◑	○	○	○

Legend: High ● Moderate ◑ Low ○

Figure 5. Relation of funding potential to development market.



existing road system. This shortfall and future needs for new construction mandate consideration of new approaches in financing highway improvements. Involvement of the private sector in funding highway improvements has been successful in some cases and has significant potential for increasing the funds available.

The potential for obtaining private funds is closely related to the strength of the real estate development sector of the economy. Experience and common sense tell us that in an adverse market, the funds available for highway improvements are diminished. Figure 5 presents a simplified graphic representation of the economic context for the use of private funds for highway improvements. This graph shows that real government expenditures for this type of infrastructure tend to rise and fall in relatively gradual cycles. The real estate development market, however, is more volatile and can experience sharp increases and declines. Although the two areas are related, their peaks and valleys do not necessarily coincide. The result is a variation in the potential for private funding.

When the expenditures of government and the private sector are both at high levels, the potential for obtaining private funds is greatest. When government spending is reduced but the development market is strong (as is currently true in some areas of the country), there is potential for private funds to replace some portion of public spending. When the development market is depressed (as is currently the case in many other parts of the country), increased public expenditure may be needed to stimulate private investment.

Review of analyses of innovative financing mechanisms for other types of transportation improvement suggests that there are some techniques that hold considerable promise. These include incentive zoning regulations that offer a developer density increases in exchange for public improvements and dedicated property taxes or special benefit assessments that set aside all or a portion of a levy on a specified group to pay for needed improvements. The lease or sale of air rights may also provide a source of private funds.

The review of current practice and examples of the use of private funds indicates that there is substantial experience and current activity in this field. Preliminary investigations suggest that there may be no way to estimate how much activity of this type exists. Moreover, experience with techniques to obtain private funds is extremely varied. Further study and analysis are needed to document past experience and extend the knowledge of useful techniques to highway planners throughout the country.

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State Highway User Taxes: Comparative Tax Structures and Current Trends

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An attempt is made to interrelate and analyze the important state highway user taxes within their historical context. First are the registration fees for automobiles and light trucks. These are sometimes referred to as first-structure taxes. Second are the motor fuel, or second-structure, taxes. Third are the heavy-truck registration, weight, and mileage taxes, or third-structure taxes. Eighteen states increased and five states decreased their automobile registration fees in 1981. Some states have changed from flat fees to fees based on weight or horsepower to encourage the energy-saving potential of lighter vehicles. Five states base their fees on weight and age or value. This is one method of trading off the conflicting values of energy conservation and not unduly penalizing low-income households that own older, heavier vehicles. A motor fuel tax is relatively inexpensive to administer and is most closely related to use, so the taxes to cover costs of providing highway service can be related to the benefits received. As a result, 26 states increased their motor fuel taxes in 1981. In order to keep up with inflation, eight states have completely converted their motor fuel tax from a cents-per-gallon to an ad valorem tax (percentage of price). Ten states have changed to a combined cents-per-gallon and ad valorem tax. User taxes for heavy trucks include graduated registration fees and weight, mileage, and gross-receipts taxes. Generally, states attempt to relate taxes to benefits obtained from highway service and the costs occasioned to the system and seek to minimize administrative costs of collecting the taxes.

Beginning in the last quarter of the 18th century and extending to the railroad era in the middle of the 19th century, tolls were levied to support turnpikes in America. Aside from these early tolls, which were very grudgingly paid, the first user tax was a registration fee. The first registration fee was enacted by New York in 1901 as a regulatory mechanism; the practice soon spread and by 1921 every state required registration fees.

The next type of user tax was the fuel tax, first adopted by Oregon in 1919. This tax spread quickly throughout the country, and by 1929, all states had levied fuel taxes. One reason for the popularity of the fuel tax was that it was related to road use to some degree. Since heavier vehicles consumed more fuel than lighter ones, the fuel tax compensated for some of the additional wear by the heavy vehicles. Another reason for the popularity of the fuel tax was its low collection and administration costs. Typically, less than 1 percent of receipts was used for those purposes.

Although registration fees and fuel taxes were

Table 1. State highway revenue trends.

Revenue Source	Percentage of Total Highway Revenue					
	1921	1935	1950	1965	1975	1980
User fee						
Fuel tax[a]	1	38	39	31	30	25
Registration fee[a]	22	21	22	14	15	16
Toll	-	2	3	6	6	5
Subtotal	23	61	64	51	51	46
Federal aid	18	23	16	39	33	38
Other						
Property and general revenue	15	1	2	1	4	7
Bonds	35	12	15	6	8	4
Investments	1	1	1	2	3	4
Local aid	8	2	2	1	1	1
Subtotal	59	16	20	10	16	16

[a]Net revenue after distributions to local government.

related to the use of the system, many felt that these taxes did not adequately reflect the added costs associated with heavy vehicles. One way to redress this problem was to levy graduated registration fees based on vehicle weight. This method, however, discriminated against heavy vehicles that were not used extensively. To compensate for this discrimination, many states granted full or partial exemption to vehicles engaged predominantly in low-mileage functions, such as farm vehicles. Other states developed weight-mileage taxes, which were based on the weight of the vehicle and the distance it traveled. The latter form of tax was usually referred to as a "third-structure" tax, which, interpreted loosely, could refer to user fees levied against heavy vehicles.

Probably because they were the first user fees levied, registration fees conventionally are considered "first-structure" taxes. These fees, somewhat similar to an entrance fee or cover charge, finance a portion of fixed costs that do not vary with use. "Second-structure" taxes are fuel taxes, which measure the use of the system. Third-structure taxes account for the impact of vehicle weights. The growth of user taxes to finance roads resulted partly from expediency and also from the need to adopt general highway finance principles. These user taxes will be discussed in detail in the following sections.

HIGHWAY REVENUE TRENDS AND FUNDING APPROACHES

State highway finance has evolved considerably over time. Table 1 (1, Tables HF-211 and DF-201; 2, Tables HF-10 and SF-1) gives state revenue trends over a 60-year period; the first subtotal represents net revenue from state user fees after distribution to local governments. At the beginning of the period, states relied heavily on registration fees, general revenue, and bonding. As the traffic-carrying function began to predominate, more reliance was placed on fuel taxes and less on general revenues and bonds. Considerable change has occurred in intergovernmental payments; federal aid has grown to more than one-third of total revenue.

The following major trends can be observed:

1. State revenues from user fees grew dramatically during the period 1921-1935 and peaked at 64 percent in 1950.
2. State revenues from user fees, as percentages of total highway revenue, have been declining since 1950. For 1980, net state user fees represented 46 percent of total revenue.
3. Of the percentage drop in revenues from user fees, two-thirds has been in fuel taxes and one-third in registration fees.
4. Federal-aid revenue grew in parallel with state user revenue until 1935 and peaked at 39 percent in 1965. Federal aid provided 38 percent of state highway receipts during 1980. If federal aid is combined with the state user fee subtotal, the combined percentage peaked at 90 percent in 1965 and has declined since then.
5. The percentage contribution from property and general revenues was insignificant (1-2 percent) during the period 1935-1965 but recently has climbed to 7 percent.
6. In 1980, the use of bonds as a revenue source was at an historic low.

Some general observations may be drawn from these trends.

Federal aid has declined through 1982 from its previous peak in 1965. With the recent doubling of the federal highway user tax, federal aid will again immediately increase to a new peak. This will put additional pressure on states to provide new funds to match the higher levels of federal aid.

With the decline in state user fees, other sources have made up the difference. However, state budget constraints may make it difficult for property taxes and general revenue to rise above the 7 percent contribution in the future. Also, the peak may have been reached on investment income with an increasing number of states using cash-flow financial management. Finally, the decline in the use of bonds as a revenue source may be related to high interest rates. This situation has resulted in increased attention on user fees. Motor fuel taxes were increased by 26 states in 1981 and 12 states in 1982. These state increases, however, may not be adequate to overcome the complex problem of matching federal aid to address the backlog of needed improvements, accelerated deterioration of existing highways, increasing cost of highway improvements, and reduced user tax revenues from existing tax rates as a result of more fuel-efficient vehicles.

The data in Table 1 demonstrate the trends in net highway user revenues, that is, net revenues after distributions to local jurisdictions. A different picture emerges if comparisons are made among states for 1981. States vary in terms of proportion of the highway system under state responsibility and proportion of revenues returned to local jurisdictions; the next comparison is made by using state highway user revenues collected divided by total state vehicle miles of travel (VMT). Figure 1 (3) shows the state highway user revenues received by each state. For all states, the average is $11/1000 VMT, or 1.1 cents/VMT, with a range from 0.7 cent in Georgia to nearly 1.9 cents in West Virginia. The differences may be partly explained by additional revenues needed to compensate for bad weather and difficult terrain. Figure 2 may also show the relative success by states in obtaining adequate user taxes to maintain highway condition and service. Information of this nature may help support the reasonableness of a user tax increase.

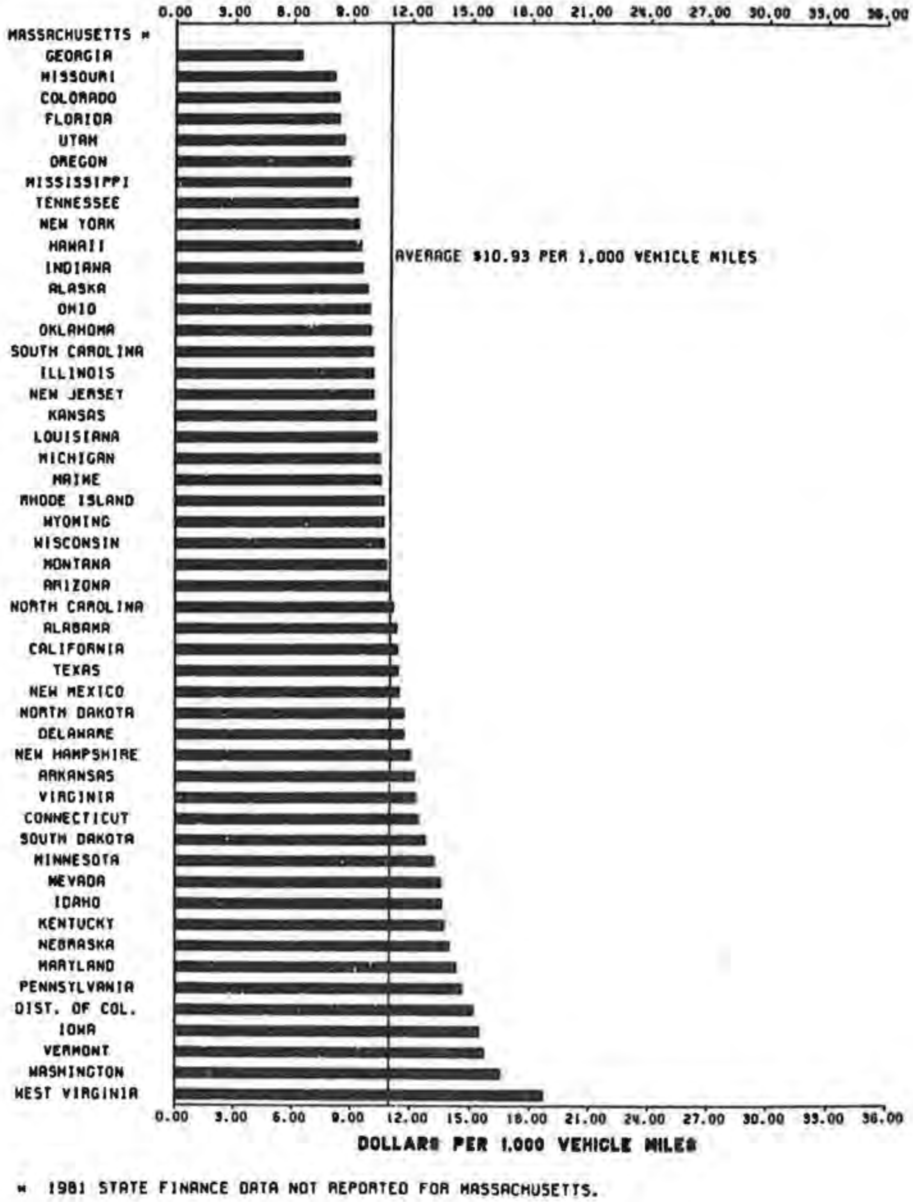
The next section examines specific state user fee structures and recent changes in registration fees, motor fuel taxes, and heavy-truck fees.

REGISTRATION FEES

Automobiles and Light Trucks

Registration fees are the earliest form of user taxes for highway purposes and are commonly referred to as first-structure taxes. They serve as an entrance fee for highway users. Vehicle registra-

Figure 1. State highway user revenue per VMT, 1981.



tions serve as both a regulatory function and a revenue source. Although the cost of administration is often large, this cost would be incurred in any event for the regulatory function. Therefore, the administrative cost from a tax viewpoint is negligible, and the incremental cost of increasing these fees is minor. However, registration fees are usually paid as a lump sum once a year. As such, it is a highly visible tax and substantial hikes are likely to be scrutinized closely by the public. First-structure taxes also include vehicle titling taxes and personal property taxes on vehicles; these will be discussed later. This section addresses automobile and light-truck registration fees. Heavy-truck registration fees are usually graduated based on weight. These fees will be discussed in the section following motor fuel taxes.

In the past, registration fees were typically a flat fee. However, as shown below (4, Table MV-103), automobile fees have changed to graduated fees; 25 states now use weight or horsepower as a basis:

Fee Basis	No. of States
Weight	16
Weight and age	4
Weight and flat fee	2
Weight and value	1
Horsepower	2
Flat fee	22
Age and value	3
Age	1
	51

Graduated registration fees have come about because of growing concerns about energy conservation and the desire to encourage the purchase of fuel-efficient vehicles. This practice, however, may not be equitable, because low-income households usually have to buy older and less-fuel-efficient vehicles. One method to trade off those conflicting values is to have a fee based on both weight or horsepower (plus) and value or age (negative) as is done by five states. A desirable attribute of including value in the basis for registration fees is that newer vehicles usually have a higher value and travel more than older vehicles.

The average registration fee for a typical automobile in 1981 was $26.23, an increase of 21.38 percent as compared with that fee in 1980. The average registration fee for a typical single-unit truck was $89.30, an increase of 9.94 percent as compared with that in 1980. Twenty-three states have changed their registration fees from 1980 to 1981, as can be seen in Table 2 (4, Table MV-103). Eighteen of these states had increases; the average increase was $8.10. Arizona had the greatest increase, $46.59, perhaps because automobile registration fees increased by only $1.50 from 1973 to 1980 as compared with much larger increases in most states. Seventeen states changed their registration fee for single-unit trucks; in 14 states the increase averaged $31.88. Four of the five states that reduced their automobile registration fees did not change their fee for single-unit trucks. The remaining state, Ohio, reduced both of these fees.

Property Taxes

A personal property tax on motor vehicles is assessed by many governmental units. Personal property taxes are similar to registration fees in application and comprise a large portion of the total taxes paid on motor vehicles in some states. They are also similar to other property taxes because they are usually not available as highway revenue. Personal property taxes are usually collected and used by local jurisdictions. Before income taxes and the growth of a money economy, personal property taxes were an important element in state and local finance. Motor vehicles are especially easy to tax because the vehicle's value is readily available from independent sources and avoidance of the tax is difficult.

As found in a 1982 study (5), most states that have a high registration fee also have a low or no property tax. States that have a high property tax usually have a low registration fee. An example of this is New Jersey, which has a registration fee two and one-half times that of Massachusetts and South Carolina. However, the total motor vehicle taxes, including the property taxes, in Massachusetts and South Carolina far exceed those in New Jersey. In fact, as shown in Figure 2 (5, p. 41), 7 of the 10 states that have the lowest combined gasoline tax and registration fees have a property tax. Of the 10 states that have the highest combined gasoline tax and registration fee, only 2 have a personal property tax.

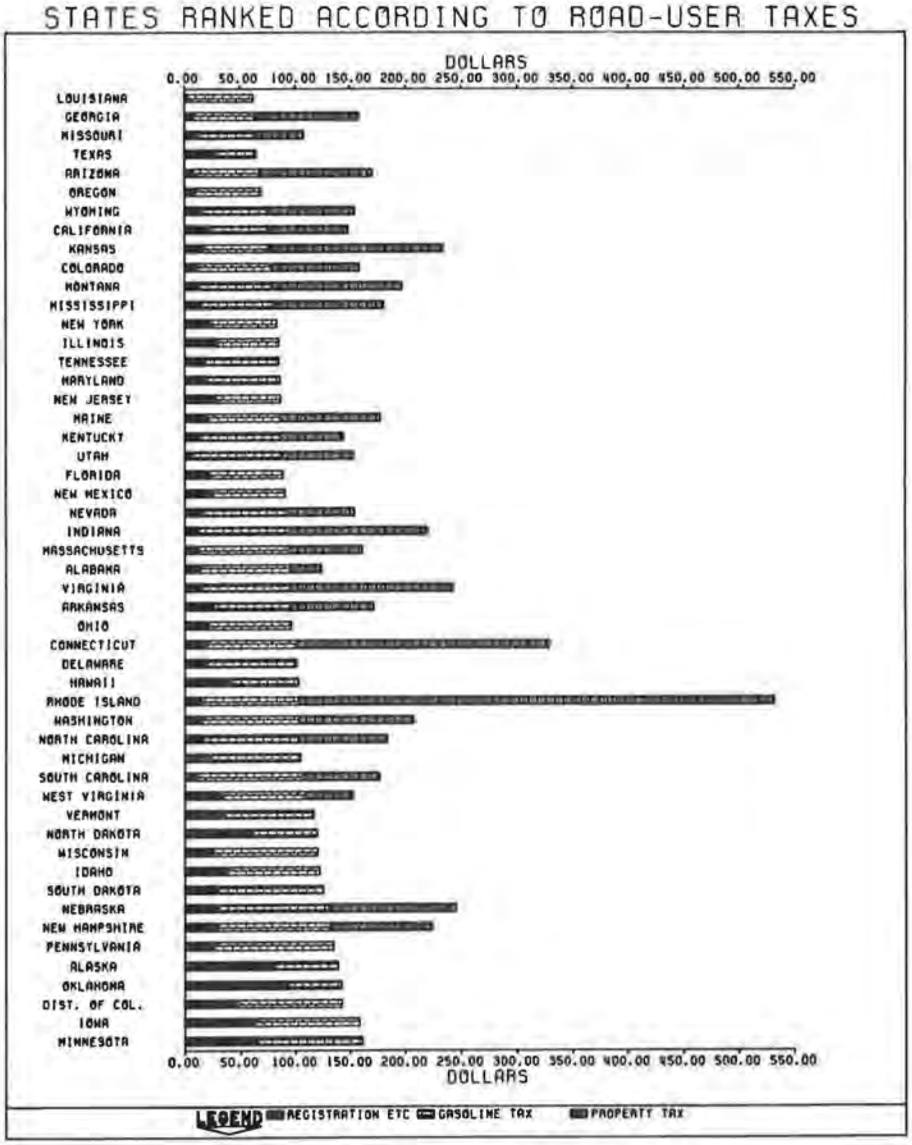
The relationship between registration fee and property taxes is illustrated by the data given in Tables 3 and 4 based on 1981 registration fees and property taxes for a 1980 four-door, medium-sized automobile (5, p. 24). [The registration fee in Table 2 may be different since the source (4, Table MV-103) contains additional fees and a different typical vehicle is used (1977 four-door sedan).] Five of the six states with the lowest registration fee also had a property tax, whereas the five states with the highest registration fee had no property tax. An exception is Louisiana, which has a registration fee of only $3/automobile and no property tax. This is a special case, since the state allocates to the highway program a substantial amount of revenue from severance taxes on oil. Connecticut, on the other hand, has a moderate registration fee of $20 but a personal property tax of $228, which is twice that of Arizona ($103).

Three out of four states examined had a substantial increase in property taxes between 1973 and 1981. Only Massachusetts showed a reduction, which may be a result of recent tax-law changes, e.g., Proposition 2 1/2. All of the states identified in Table 4 except Louisiana had an increase in registration fee since 1973.

Table 2. 1981 state motor vehicle registration fees and changes from 1980.

	1981 Registration Fee and Change from 1980			
	Automobile		Truck (single-unit, nonfarm)	
Item	Fee ($)	Change from 1980 ($)	Fee ($)	Change from 1980 ($)
State				
Alabama	13.75		45.50	
Alaska	30.00		80.00	
Arizona	54.59	+46.59	322.62	+245.62
Arkansas	30.00		91.00	
California	22.00	+11.00	147.00	+74.00
Colorado	10.10	−25.70	107.75	
Connecticut	20.00		91.00	+3.25
Delaware	20.00		66.80	
District of Columbia	42.50		163.50	
Florida	22.75	+0.75	83.75	+6.25
Georgia	8.00		8.00	
Hawaii	48.08		132.05	
Idaho	33.00	+5.00	30.60	+0.60
Illinois	30.00		130.00	
Indiana	60.25	+12.00	100.75	+0.50
Iowa	43.00	+3.00	110.00	
Kansas	19.50		75.00	
Kentucky	12.50		31.00	
Louisiana	6.00		100.00	
Maine	20.00		70.00	
Maryland	30.00		49.00	
Massachusetts	10.00	+3.00	98.00	+28.00
Michigan	23.00		243.00	
Minnesota	38.00	+11.00	62.00	
Mississippi	10.25		65.75	
Missouri	11.50	−9.00	50.50	
Montana	12.00		34.50	
Nebraska	16.50		86.50	
Nevada	16.00	+7.50	43.00	+8.00
New Hampshire	28.80	+4.80	88.80	+4.80
New Jersey	28.00	+4.00	126.50	+4.25
New Mexico	12.50		52.50	
New York	24.75	−0.86	70.00	
North Carolina	16.00	+3.00	144.40	+21.20
North Dakota	38.00	+5.00	47.00	+15.00
Ohio	21.00	−0.50	126.00	−0.50
Oklahoma	50.00		98.10	
Oregon	10.00		45.00	
Pennsylvania	24.00		132.00	
Rhode Island	17.00		62.00	
South Carolina	10.00		63.00	−15.00
South Dakota	21.00		60.00	
Tennessee	19.00	+0.50	62.50	+7.50
Texas	22.30		96.82	
Utah	7.00	−1.00	35.00	
Vermont	36.00	+4.00	172.20	
Virginia	15.00		32.40	
Washington	20.10	+9.60	65.00	+9.60
West Virginia	38.00	+8.00	58.00	−0.30
Wisconsing	25.00	+7.00	168.00	
Wyoming	15.00		60.00	
Avg	26.23	+4.73	89.50	+25.16
Last year's avg	21.61		81.41	
Percent change	21.38		9.94	

Figure 2. State road user and personal property taxes on a medium-weight passenger car.



The existence of a personal property tax on vehicles has obvious implications for the amount of highway revenue available to a state, because the opportunity to increase those revenues is hindered due to the high vehicle property taxes.

Property taxes, like registration fees, in some states are dependent on vehicle age, value, and other factors. The two fees are almost identical in their basis for taxation in states where registration fees are based on age or value.

Titling Taxes

First-structure taxes also include titling taxes on new and used vehicles. Titling taxes are similar to a state sales tax because they are based on a percentage of the vehicle purchase price. A titling tax is imposed when new, used, or transferred vehicles are first titled in a state, and titling taxes are predominantly dedicated to highways. The alternative sales tax is imposed on new and used vehicles when bought and the proceeds go to general state revenues, although some legislatures have appropriated portions of the revenues for transportation purposes.

Titling taxes were the only motor vehicle tax that kept pace with inflation and in fact exceeded it. In 1980, 10 states (Delaware, Idaho, Kentucky, Maryland, New Mexico, North Dakota, Texas, Vermont, Virginia, and West Virginia) and the District of Columbia imposed a titling tax in lieu of a sales tax on vehicles. However, in Delaware, District of Columbia, and Texas, the proceeds go into the general fund. Titling tax revenues increased by 269 percent during the 1970s in 9 of the 10 states and the District of Columbia. In the same period, registration fees increased by about 25 percent. Titling tax revenues from motor vehicle purchases accounted for one-third to two-thirds of all motor vehicle revenues in these states. Moreover, the receipts represent 13-34 percent of total road user revenues generated by these states, as can be seen in Table 5 (2, Tables DF and MV-2; 4, Table MV-106; 6). The importance of titling taxes as a source of revenue has been dis- cussed elsewhere (7).

MOTOR FUEL TAXES

A motor fuel tax has many advantages:

1. It measures use of the highway system,

Table 3. Registration fees and property taxes on medium-sized automobile in selected states ranked according to combined tax, 1981.

State	Registration Fee ($)	Property Tax ($)	Total ($)
Connecticut	20.00	228.00	248.00
Arizona[a]	8.00	103.12	111.12
Indiana[a]	12.25	126.00	138.25
Oklahoma	92.61	0	92.61
Colorado	11.10	80.88	91.98
South Carolina	10.00	70.50	80.50
Massachusetts	10.00	67.00	77.00
Utah	5.00	64.71	69.71
Iowa	63.00	0	63.00
District of Columbia	42.00	0	42.00
Vermont	36.00	0	36.00
New Jersey	25.00	0	25.00
Louisiana	3.00	0	3.00

[a]The property tax is an "in lieu" tax, which is paid with the registration fee. It has been included as part of the registration fee in previous tables.

Table 4. Registration fees and property taxes on medium-sized automobile in selected states ranked according to registration fee, 1981.

State	Registration Fee ($)	Property Tax ($)
Oklahoma	92.61	0
Iowa	63.00	0
District of Columbia	42.00	0
Vermont	36.00	0
New Jersey	25.00	0
Connecticut	20.00	228.00
Indiana[a]	12.25	126.00
Colorado	11.10	80.00
South Carolina	10.00	70.50
Massachusetts	10.00	77.00
Arizona[a]	8.00	103.12
Utah	5.00	64.71
Louisiana	3.00	0

[a]The property tax is an "in lieu" tax, which is paid with the registration fee. It has been included as part of the registration fee in previous tables.

2. It is inexpensive to administer,

3. It is relatively painless for the taxpayer because the tax is distributed over each refill, and

4. It can be collected from out-of-state vehicles.

Since almost all gasoline is consumed by motor vehicles, the tax is collected at the wholesale distribution level rather than at the retail level. This feature also serves to reduce administrative costs. Those who do not use highways also pay the tax, but they can generally claim a refund. Not all of them do, however, and some states set aside an estimated amount of unclaimed refunds to use for nonhighway transportation purposes such as airports, marinas, and snowmobile trails.

Diesel fuel has mixed uses. Because a substantial share of diesel fuel is used for nonhighway vehicles (e.g., farm tractors and construction equipment), this tax is frequently collected from retailers and not from distributors. However, comparisons of travel by diesel vehicles on the highway and expected miles per gallon against receipts from gallons of diesel fuel taxed indicate that a substantial amount of diesel fuel used for highway purposes may escape taxation.

Motor Fuel Tax Increases

Fuel taxes are an extremely productive source of revenue. Nationwide, each 1-cent tax increment

Table 5. Selected motor vehicle revenues, 1980.

Item	Titling Tax ($)	Total Motor Vehicle Revenue: Amount ($)	Total Motor Vehicle Revenue: Titling Tax (%)	Total Highway User Revenue: Amount ($)	Total Highway User Revenue: Titling Tax (%)
State					
Delaware	8 112[a]	24 864	32.6	53 090	15.3
District of Columbia	10 441[a]	29 620	35.2	46 707	22.4
Idaho	829	41 504	2.0	90 298	0.9
Kentucky	89 065	153 164	58.2	342 708	26.0
Maryland	122 265	221 123	55.3	407 598	30.0
New Mexico	16 719	59 371	28.2	129 873	12.9
North Dakota	2 004	31 824	6.3	62 263	3.2
Texas	423 622[a]	804 613	52.6	1 282 057	33.0
Vermont	10 761	33 206	32.4	54 886	19.6
Virginia	62 798	183 252	34.3	467 006	13.4
West Virginia	49 001	99 854	49.1	200 925	24.4
Weighted avg			47.3		25.4

[a]Considered to be a highway user tax; however, it is not dedicated and may not necessarily be appropriated to the highway fund.

produces about a billion dollars in revenue. The average weighted state fuel tax in 1979 was 8 cents. Motor fuel taxes were increased by 14 states in 1979, 12 states in 1980, 26 states in 1981, and 12 states in 1982. In four states that had an indexed motor fuel tax, the tax decreased in 1982 [Table 6 (4, Table MF-121, modified to show portion of sales tax dedicated to highways)].

Although fuel taxes have been a mainstay of highway finance, generally they have not kept up with inflation. As can been seen in Table 1, motor fuel taxes provided 30 percent of highway revenue in 1975 but only 25 percent in 1980. When fuel consumption was increasing steadily, fuel tax receipts increased automatically. Recent years have seen a leveling and even a decline in fuel consumption. With mandated fuel-efficiency standards and increasing fuel prices, an increase in future fuel consumption is unlikely despite possible increases in travel.

In order to keep up with inflation, an increasing number of states have converted completely or partly to an ad valorem (indexed) tax on motor fuel. The tabulation below indicates that eight states have motor fuel taxes that are completely indexed at 1- to 12-month intervals.

State	Type of Tax
District of Columbia	Indexed to consumer price index (effective Jan. 1982)
Indiana	Retail
Kentucky	Wholesale (9 percent)
Maryland	Wholesale (10 percent, effective July 1, 1984)
Massachusetts	Wholesale (10 percent)
New Mexico	Indexed to wholesale; maximum rise, 1 cent/year
Rhode Island	Wholesale (10 percent)
Washington	Retail (10 percent)

Indiana has an ad valorem tax of 10 percent of $1.00 and 8 percent of the next $0.50 of the retail fuel price before taxes that is used for highways. In addition, Indiana has a 4 percent sales tax on the retail fuel price before taxes that is used for mass transportation and general revenue purposes. Maryland increased its motor fuel tax to 11 cents in 1982. A future increase to 13.5 cents will be effective June 1, 1983, and 13.5 cents per gallon will be the floor or minimum tax when it is converted to an ad valorem tax of 10 percent of wholesale price effective July 1, 1984.

Several states have retained a flat (unit) gallonage tax and added a small ad valorem tax, as shown below:

State	Type of Tax
California	7 cents plus 4.75 percent retail
Georgia	7.5 cents plus 3.0 percent retail less state tax
Hawaii	8.5 cents plus 4.0 percent retail
Illinois	7.5 cents plus 4.0 percent retail
Michigan	11 cents plus 4.0 percent retail less state tax
Mississippi	9 cents plus 5.0 percent retail
Nebraska	11.5 cents plus 2.0 percent (variable) retail
New York	8 cents plus 4.0 percent retail less state tax
Ohio	7 cents plus 3.3 cents indexed to fuel consumption and maintenance cost
Pennsylvania	11 cents plus 3.5 percent wholesale less taxes
Virginia	11 cents plus 3.0 percent wholesale less taxes

In some cases, the legislature has been more receptive to indexing part of the tax increase than to indexing the total tax. In other cases, state legislatures have gradually dedicated an increasing proportion of the existing sales tax on motor fuel to highways. Georgia, Illinois, and Nebraska dedicate the sales tax revenue to highways. Ohio has an additional 3.3 cents/gal that is indexed to the maintenance cost index and inversely to motor fuel consumption. Pennsylvania has a 3.5 percent fran-

Table 6. Gasoline and diesel fuel tax and changes by year.

	Fuel Tax (cents/gal)									
	1979		1980		1981		1982		1983	
Item	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
State										
Alabama	7	8	11	12						
Alaska	8									
Arizona	8						10		12	
Arkansas	9.5	10.5								
California	7								9	
Colorado	7				9					
Connecticut	11									
Delaware	9				11					
District of Columbia	10		11		13		14			
Florida	8									
Georgia	7.5[a]									
Hawaii	8.5									
Idaho	9.5				11.5		12.5			
Illinois	7.5[b]									
Indiana	8		8.5		10.5		11.1			
Iowa	10	11.5			13	13.5	13	15.5		
Kansas	8	10								
Kentucky	9				10.4		10.0			
Louisiana	8									
Maine	9									
Maryland	9						11		13.5	
Massachusetts	8.5		9.8	10	11.4		10.4			
Michigan	11	9	11							
Minnesota	9		11		13					
Mississippi	9	10			9	10[c]				
Missouri	7									
Montana	9	11								
Nebraska	10.5		13.6		13.9		14			
Nevada	6				10.5		12			
New Hampshire	11				14					
New Jersey	8									
New Mexico	7		8		9		10			
New York	8									
North Carolina	9				12					
North Dakota	8									
Ohio	7				10.3		11.7			
Oklahoma	6.58									
Oregon	7				7		8			
Pennsylvania	11				11[d]					
Rhode Island	10				12		11			
South Carolina	10		11		13					
South Dakota	9		12		13					
Tennessee	7	8			9	12				
Texas	5	6.5								
Utah	9				11					
Vermont	9				11					
Virginia	9		11				11[e]			
Washington	12				13.5		12			
West Virginia	10.5									
Wisconsin	7		9		13					
Wyoming	8									
No. of increases	14		12		26		12			

[a] Plus 3 percent of sales tax.
[b] Plus 4 percent of sales tax.
[c] Plus 5 percent of sales tax; Mississippi's highway-revenue proceeds from sales tax are limited to $42 000, $50 000, and $60 000 for FY1981, 1982, and 1983, respectively.
[d] Plus 3.5 percent of sales tax.
[e] Plus 3 percent of sales tax.

chise tax on gross receipts, which is at the point of first sale of motor fuel in Pennsylvania (wholesale level). The franchise tax revenue is dedicated to highways. Beginning in 1981, Mississippi gradually increased the proportion of its motor fuel sales tax dedicated to highways. California's sales tax was instituted in the early 1970s and generally funded mass transportation, but it was changed in 1981 so that by 1986 it will be split fifty-fifty between highway purposes and mass transportation. Hawaii's sales tax on motor fuel has been going to general revenues, but for 1981-1984, the revenues will be used for highway purposes. Part of Michigan's sales tax on motor fuel is used for mass transportation.

Exemptions and Special Vehicles

When highway revenues are evaluated, the impacts of exemptions and special vehicles such as those that use gasohol and electricity should be considered. The use of these fuels conserves the U.S. supply of oil. However, motor fuel use and tax revenues are reduced, despite the continued use of the highways.

Electric vehicles do not pay a gasoline tax but receive the benefits of a highway system without adequately paying the costs of maintaining and improving the system. Several possibilities to rectify this situation are a graduated registration fee based on mileage similar to that for heavy trucks, an additional property tax, or a tax on vehicle parts. For example, a state may choose not to impose a high tax the first year (e.g., sales tax, titling tax) so as not to discourage the purchase of electric vehicles but to impose a large registration fee or property tax to compensate for highway system use.

The other item to consider is gasohol. To encourage production and use of alcohol as a means of reducing U.S. dependence on foreign oil, the federal government and many states have exempted gasohol from some or all taxes. The loss in revenue has been significant in some states. Iowa estimates a loss of $35.6 million for FY 1982 and 1983 because of gasohol use. At the national level, the tax exemption on gasohol is expected to result in a loss of $115 million to the Highway Trust Fund for 1985.

HEAVY-TRUCK TAXES

Studies have shown that the fuel tax does not impose charges commensurate with cost responsibilities for very heavy trucks. For this reason, most states levy graduated registration fees based on vehicle weight; others impose weighted axle-mile or ton-mile charges; some impose gross receipts taxes on certain motor carriers; and a few states use a combination of these.

The basis in 1981 for determining graduated registration fees for heavy trucks is summarized below (4, Table MV-103). Thirty-eight states based the fees on weight, usually defined as the maximum allowable gross vehicle weight for that truck. Since some carriers handle light cargo loads in which the space capacity is filled before the vehicle load capacity is reached, provisions are frequently made to allow an operator to declare the gross vehicle weight to be the weight at which the vehicle will operate.

	No. of States	
Fee Basis	Tractor	Semitrailer
Flat fee	-	32
Weight	38	10
Flat fee and weight	8	4
Flat fee or weight	-	2
Weight and age	5	1
No registration fee	-	2
	51	51

Graduated registration fees usually discriminate against low-mileage operators. To correct for this, many states have also varied the fee by vehicle classification or use. Low-mileage users such as farmers and lumber haulers might pay lower fees, whereas high-mileage users such as common carriers would pay higher fees. Consideration for low-mileage operators may have helped keep these fees lower then they should be.

Registration Fees

Registration fees for heavy trucks have changed to a degree similar to that for automobiles and single-unit trucks. The graduated fee structure has shown the greatest changes. Twenty-five states changed heavy-truck registration fees from 1980 to 1981, as shown in Table 7 (4, Table MV-103). Twenty of these states increased their registration fees. The average increase was $202.28, whereas the average reduction of the four remaining states was $38.50, which gives a net change of $163.75. When all the states are considered, the average change was 11.88 percent and the average registration fee was $701.23. The average registration fee in 1980 was $626.77.

In comparing registration fees for heavy trucks with those for light single-unit trucks, the average ratio is 9.08:1; the largest ratio is 24.9:1 and the smallest is 1.4:1. Colorado is the only state to have a lower registration fee for heavy trucks than for single-unit trucks. The reason is that Colorado has a ton-mile tax on heavy trucks, which more directly measures the use of the system. The range of registration fees nationwide for heavy trucks was from $33.00 to $2159.55 as compared with $8.00 to $322.02 for single-unit trucks. If the wide range in the ratio of heavy-truck registration fees to automobile and single-unit registration fees is noted, some states may wish to evaluate their fee structure.

Weight and Mileage Taxes

A few states have gone beyond simply levying graduated weight fees. To compensate more fully for the cost imposed by heavy trucks, a weight-mileage fee has been applied. The basis for this tax also varies: Two states (Colorado and Wyoming) use ton miles and six states (Idaho, Nevada, New Mexico, New York, Ohio, and Oregon) use weight miles.

Some of these states give operators the option of substituting mileage fees for the graduated registration fee. This allows low-mileage operators the opportunity to reduce their overall payments.

Two states--Virginia and Kentucky--require trucks with three or more axles to pay a motor fuel surtax of 2 cents/gal of fuel.

Finally, a few states (Arizona, California, Pennsylvania, and Washington) levy a gross receipts tax on certain operators, usually common carriers. The principle of this mechanism is to tax operators for the differential benefits they receive from highways. The underlying theory behind all these taxes is that heavy trucks either cause greater costs for highway improvements and maintenance or receive special benefits from the highway system. Exactly how these costs or benefits are determined is the objective of cost-allocation studies.

The cost to collect weight and mileage taxes and the burden imposed on operators can be high. The trucking industry has been particularly vociferous in their opposition to the weight-mileage fees. Claiming that this tax imposed an extraordinary paperwork burden, the industry mounted a campaign during the 1950s to prevent the spread of this form of tax. A study conducted by the University of Mississippi concluded that although the paperwork involved is extensive, much of the required data are also needed for the reciprocal agreement reports. The weighing stations likewise serve a dual function. They help prevent excessive loads from damaging the highways as well as provide proper taxing reports. The cost of collecting the weight-mileage taxes is much higher than that for other user taxes. This cost varies from 3 to 10 percent of the total revenue levied. Overall, the states collected about $1.9 billion in truck registration fees and about $205 million in mileage taxes during 1979.

Due to the variety of methods as well as the particular rates used, the costs of operating similar trucks in different states vary widely. Also, the ratio of payments for a heavy truck to those for a medium-weight truck could vary from as low as 1.4:1 in New Mexico to a high of 24.9:1 in Kentucky and Missouri. If Interstate operators were allowed to register their trucks wherever they desired, they would obviously select the states that had the lowest taxes. To prevent this from happening, most states require operators to file extensive reports detailing the extent of their operations within that state.

Regional Compacts Relating to Heavy-Truck Fees

Three agreements or compacts have been enacted among regional groupings of states that specify how trucks registered in one state will be treated when they are operated in another. Such agreements may waive any additional taxes being imposed by the nonhost state provided that reciprocal treatment is accorded.

The three regional compacts are the Multi-State Reciprocal Agreement, the Uniform Vehicle Registration Proration and Reciprocity Agreement (UPRA), and the Internationl Registration Plan (IRP). IRP has the largest membership; 26 states are now participating. There are three states under UPRA that are not members of IRP. IRP and UPRA operate on a proration basis. The operator pays a portion of a state registration fee based on the expected fleet mileage to be traveled there. This is done by the following calculation:

(In-state fleet miles)/(total fleet miles) x total state registration fee.

Under IRP, the carrier files with the base state and receives one plate and cab card. This allows travel in member jurisdictions where fees have been apportioned. Under UPRA, the carrier must file individually with each member state in which travel is to occur and receives a base plate plus identifying stickers that must be attached to a second plate. The Multi-State Reciprocal Agreement has a membership of 16 states, some of whom are also members of IRP.

OTHER STATE FUNDING SOURCES

In addition to highway user revenue, some states receive revenue from nonuser sources. In fact, nonuser sources of state highway revenues have increased substantially in the last 15 years; they rose from 10 percent in 1965 to 16 percent in 1980. As shown in Table 8 (2, Table SF-1; 8) there are several nonuser taxes that are allocated to highways. In Massachusetts and Mississippi, a portion of the cigarette tax is allocated to the highway fund. This makes up 4.4 percent of the total highway revenue in Massachusetts and 1.6 percent in Mississippi. In Maryland, 3.75 percent of the 7.0 percent corporate tax goes to the state's Transportation Trust Fund; the dedicated portion pays for

Table 7. State motor vehicle heavy-truck registration fees.

State	Heavy-Truck Registration Fee 1981: Fee ($)	Heavy-Truck Registration Fee 1981: Change from 1980 ($)	Ratio Heavy-Truck Fee to Single-Unit Truck Fee[a]	State	Heavy-Truck Registration Fee 1981: Fee ($)	Heavy-Truck Registration Fee 1981: Change from 1980 ($)	Ratio Heavy-Truck Fee to Single-Unit Truck Fee[a]
Alabama	346.00		7.6	Nebraska	814.00	+1.00	9.4
Alaska	230.00		2.9	Nevada	167.00	+30.00	3.9[b]
Arizona	2159.55	+1569.55	6.7[b]	New Hampshire	532.80	+100.80	6.6
Arkansas	1044.00		11.5	New Jersey	637.50	+17.00	5.0
California	1081.00	+451.00	7.4[b]	New Mexico	75.50		1.4[b]
Colorado	33.00		0.3[b]	New York	519.00		7.4[b]
Connecticut	740.00	-72.00	8.1	North Carolina	841.00	+117.00	5.8
Delaware	362.40		5.4	North Dakota	1016.00	+221.00	21.6
District of Columbia	700.00	-71.00	4.3	Ohio	663.00	-1.00	5.3[b]
Florida	474.50	+2.50	5.7	Oklahoma	655.25		6.7
Georgia	108.00		13.5	Oregon	185.00		4.1[b]
Hawaii	536.60		4.1	Pennsylvania	369.00		2.8[b]
Idaho	135.00	+33.00	4.4[b]	Rhode Island	410.00		6.6
Illinois	1492.00		11.5	South Carolina	586.00	+73.00	9.3
Indiana	625.50	+110.00	6.2	South Dakota	415.00	+20.00	6.9
Iowa	1520.00		13.8	Tennessee	1010.00	+125.00	16.2
Kansas	1200.00		16.0	Texas	735.60		7.6
Kentucky	771.50		24.9	Utah	510.00	+305.00	14.6
Louisiana	490.00		4.9	Vermont	1869.10	+209.80	12.2
Maine	700.00		10.0	Virginia	680.00		21.0
Maryland	555.00		11.3	Washington	540.64	+148.20	8.3[b]
Massachusetts	534.00	+144.00	5.4	West Virginia	628.50	-10.00	10.8
Michigan	798.00		3.3	Wisconsing	1176.00	+50.00	7.0
Minnesota	1330.50	+270.00	21.5	Wyoming	120.00		2.0[b]
Mississippi	608.50		9.3				
Missouri	1259.00	+250.00	24.9				
Montana	774.00		15.3				

[a]See Table 2 for single-unit truck fees. [b]States with additional gross receipts or weight-mileage tax.

debt service, highway costs, and other transportation costs, including the state's share of costs for mass transportation systems. This amounted to $5 366 270 in 1980 or 1.4 percent of the revenue allocated to the trust fund. In South Dakota, 10 percent of the game and fish license fee ($221 525 in 1980) is allocated to the counties for highway purposes. Severance taxes and mineral lease revenues are allocated to highway programs in 10 other states.

Severance Taxes

Ten states collect a severance tax and/or mineral lease revenue (e.g., for oil or coal) that is partly allocated to the highway program. The procedures used to collect this revenue and the allocation of the revenue to the highway programs vary between states. Revenue allocated to the highway programs from severance taxes and mineral leases ranges from $445 710, which is 0.2 percent of Kansas' total highway revenue, to $55 964 000, which is 58.6 percent of Wyoming's total highway revenue. In New Mexico, severance taxes comprise nearly 14 percent of highway program revenue. Excluding Kansas, Wyoming, and New Mexico, severance taxes for the remaining seven states comprise about 7 percent of total highway revenues.

Alaska and Louisiana allocate all severance taxes and mineral lease revenue to the state general fund; these states are discussed below. Several states collect a severance tax that is not directly allocated to the state's highway program. Often bonds are issued based on the severance tax revenue or some other revenue source. A portion of the revenue generated from the bonds may then be allocated to the highway program. These other fees can make a significant contribution to the state's highway programs.

Table 8. Other taxes dedicated to highways, 1980.

State	Special Type of Tax	Amount ($)	Percentage of Total State Highway Revenue
Arizona	Mineral lease	854 192	0.4
Arkansas	Severance tax	2 476 182	
	Mineral lease	83 820	1.1
Kansas	Mineral lease	445 710	0.2
Kentucky	Coal severance tax	33 194 680	6.5
Maryland	Corporate income tax	5 366 270	1.4
Massachusetts	Cigarette tax	17 600 000	4.4
Mississippi	Cigarette tax	5 005 540	1.6
Montana	Mineral lease	3 580 444	
	Coal tax	1 786 708	7.0
New Mexico	Severance tax	20 314 705	13.7
North Dakota	Gas and coal production tax	4 580 022	6.7
Oklahoma	Oil severance tax	28 988 239	6.7
South Dakota	Game and fish license	221 525	0.3
Wyoming	Coal severance tax	16 361 000	
	Mineral royalties (federal)	39 603 000	58.6

General-Fund Appropriations

There are eight general-fund states. This means that all revenue received by the state goes into the state's general fund. Then, through legislative appropriations, a certain amount is allocated for highway purposes. Highway appropriations for four states were greater than highway-user receipts. Alaska and Louisiana receive substantial revenues from severance taxes and mineral leases. This allows the states to keep highway user taxes low and to appropriate amounts substantially above highway-user receipts for highway purposes. Delaware is a general-fund state without significant severance taxes; however, appropriations for highway purposes for 1981 were 20 percent greater than highway-user receipts. In New York, 1981 appropriations for highway purposes were 4 percent greater than user receipts. Although New York substantially funds its highway program, the average appropriation from general funds for the 43 states with dedicated highway trust funds equals an amount 7 percent greater than user receipts. Table 9 (9, Tables DF and SF-1) contains these recent trends.

Four general-fund states appropriated less money for highway purposes than was received from highway-user revenues. In the case of Connecticut and District of Columbia, the remainder of highway-user receipts generally matched that appropriated to mass transportation. However, in the case of New Jersey, only $234 476 000, or 45 percent, was appropriated for highway purposes and $253 197 000 was used for state general purposes out of the $519 592 000 received in highway-user revenues.

CONCLUDING OBSERVATIONS

Efficiency and equity are important concerns. Some observers of the current decline of the public works infrastructure in the large cities believe that it reflects inadequate investment versus consumption and the need for increased application of user charges. Investment in water systems is an example outside the realm of highways. Cities that have investments in water systems tied directly to dedicated user charges have water systems in far better shape than those that do not (10).

Table 9. Appropriations for highway purposes by general-fund states, 1981.

State	Highway-User Revenue ($000 000s)	Appropriations ($000 000s) From User Revenue	Appropriations ($000 000s) From General Funds	Appropriations ($000 000s) Total	Percentage of Highway-User Revenue Used 1980	Percentage of Highway-User Revenue Used 1981
A:						
Alaska	28.509	28.509	130.885	159.394	549	559
Louisiana	256.147	256.147	315.149	571.296	174	223
Delaware	52.072	52.072	10.356	62.428	116	120
New York[a]	738.120	738.120	30.045	768.165	103	104
B:						
Connecticut	239.681	208.014	0	208.014	88	87
Rhode Island	59.313	37.269	0	37.269	70	63
District of Columbia	50.094	32.676	0	32.676	42	65
New Jersey	519.592	234.476	0	234.476	40	45

Notes: A = states that appropriated more funds than they received in highway-user revenue. B = states that appropriated less funds than they received in highway-user revenue.

[a]Funds are partly dedicated.

There are a number of highway user and nonuser taxes and combinations thereof in use. The objective of a state highway agency in structuring its taxes should be to follow good highway-finance principles. Also, the objectives should be the same as those contained in a highway cost-allocation study. For example, the objectives of the 1978-1981 National Highway Cost-Allocation Study were to develop equitable and efficient highway user charges. "Equitable" means the fair allocation of costs among vehicle classes where the revenue obtained should correspond to costs caused or occasioned by such vehicle classes. Economic efficient charges are achieved when the price of a trip equals the extra (marginal) costs caused by that trip, but this is very difficult to put into practice. Economic efficiency, however, underlies the whole concept of using highway user charges to finance highway improvements and operations. Over the long run, motor fuel taxes for all vehicles and weight and mileage taxes for heavy vehicles appear to best correspond to use and to long-run marginal costs.

For example, problems develop when part of the highway user charges rises with inflation and part does not. As pointed out previously, there are 10 states with titling taxes. The increase in highway revenue from the titling tax has on the average exceeded the rate of inflation, whereas motor fuel tax revenues have risen slowly and in some cases decreased. Logically, other states may focus on the titling tax as a good means of increasing their highway revenues. However, considerations of equity in tax burden and good highway-finance principles suggest that increased revenue from a titling tax should be considered only after an increased motor fuel tax has been considered.

Personel property taxes on vehicles, which generally accrue to local general revenues and not to the highway fund, provide another example that shows how some taxes are indexed to inflation and others are not. Based on highway cost-allocation principles, there are at least five problems with placing major reliance on the vehicle property tax, the titling tax, or the vehicle sales tax. First, they are not related to use of the highway system vis-à-vis the motor fuel tax. Therefore, they act contrary to the concept of economic efficiency stated above. Second, it appears that generally owners of automobiles and light trucks overpay their share of highway costs. Third, highway tax increases due to inflation that affect such owners would make such user charges even more inequitable. Fourth, economists point out that adverse impacts from deviating from economic efficiency are complex and affect the national, state, and local economies in other ways. Fifth, they make it much more difficult to raise nonindexed taxes such as most motor fuel taxes.

As a practical matter, the state highway agency is primarily concerned with whether or not vehicle property and sales taxes adversely affect proposals to raise highway user taxes. One possible solution may include seeking a lower vehicle property tax rate so that increased or ad valorem highway user taxes may be enacted.

In conclusion, states are urged to first seek increases in motor fuel taxes and weight and mileage taxes, since these are most closely related to use. If such use-related taxes are insufficient to fund the highway program, then states may look to first-structure taxes such as registration fees and titling taxes to fund the program. In developing the amount of the tax increase, the objectives of equity and balance should be kept in mind, so that the amount of the tax imposed corresponds to the costs caused by each vehicle class. Some states may be able to use a financing package that combines bonds for capital improvements with increased user fees for debt service and expected maintenance.

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Financing County Roads: An Evolution in Progress

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As new methods of raising and allocating revenues to maintain local roads and bridges are debated in the political arena, the condition of those facilities continues to worsen. Cities and counties are faced with increasing competition for funds that have not kept up with rising construction costs. The problem of programming county road and bridge funds in Indiana is described. The state's local-option highway user tax is presented as an innovative revenue-generation method available to county governments. The financial constraints on a county's ability to fund all legitimate projects are illustrated by two distinctly different cases in Indiana. The resolution of these two cases gives clues to a set of measures that must be considered as we move through an evolutionary period in highway financing and programming.

Recent years have seen a continuation--even an acceleration--of two disturbing trends: the deterioration of U.S. roads and highways and the failure of highway maintenance revenues to keep pace with maintenance costs. All levels of government sought new sources of revenues to apply to the road system for which it was responsible. In most cases, they were not successful. Raising taxes is never politically desirable, so as each governmental body sought to provide services within a shrinking budget (in real terms), some of those services did not receive high priority.

Among the most postponable of local governmental services seems to be road maintenance. Normal road maintenance activities are deferred in the name of economy and with the hope that the facilities can survive another year. Such gambles often do not succeed. Routine maintenance deferred brings on a premature need for more extensive work, such as resurfacing. Postponed resurfacing can hasten the day that reconstruction is needed. This penny-wise and pound-foolish approach can lead to greater expenditures and, in the meantime, to poorer service to highway users.

Even as these struggles were taking place in statehouses and county halls, a philosophy was taking shape in Washington, D.C. In February 1982, the Reagan Administration announced its New Federalism proposals. An important element involved the gradual reduction of federal funds available to the states for highways and other transportation facilities. At a time of the states' above-mentioned struggles, this was not a development welcomed by many of them. Even if the initial proposal carried with it a transfer of funds, in the not-too-distant future the states would have added responsibilities, which would include those of raising additional revenue. State and local highway routine maintenance activities have never been eligible for federal funds, but Washington's grants to projects in other categories made more state-level funds available for maintenance. If highway funds are no longer forthcoming from the federal government, state and local governments will be facing serious choices. If they are unwilling or unable to replace these federal revenues, do they skimp even further on maintenance to create funds for large capital projects? Or are such large projects left undone and postponed, which would lead to a highway network that provides an ever-diminishing level of service?

The recently enacted 5-cent increase in the federal gasoline tax will provide a substantial increase in federal assistance to states and local governments. But the need to repair U.S. roads and bridges is so great that the $5.5 billion increased annual aid is only a fraction of what is needed (1,2). Furthermore, these funds are for capital projects only. Their impact on local road maintenance will be indirect and dependent on a particular state's method of allocating the funds. The Indiana Transportation Coordinating Board has determined that the state's $48 million share of the new assistance would be split 75 percent/25 percent; the state would receive the bigger part. The $12 million for cities and counties will be awarded on a project-by-project basis. Some cities and counties will get none of the $48 million. Among those that do, whether the new capital funds cause a rise or decline in a local agency's funds available for maintenance depends on whether the project would have been attempted without federal assistance and on the degree to which local matching funds are required. Although the new revenues generated by the Surface Transportation Assistance Act of 1982 are welcome, their availability at the local level is by no means guaranteed, and their impact on maintenance is uncertain at best.

In this paper, the impacts of the physical and fiscal trends pertaining to county roads in Indiana are examined. In just the past few months, we in Indiana have seen developments that we feel are symptomatic of the nationwide situation in local highway financing. We may be watching the early stages of an evolution in highway maintenance responsibilities, an evolution that involves a greater local commitment to better roads and the revenue generation that commitment requires. The problems of Indiana roads may not be unique, but some of the solutions being tried may be of interest to many areas of the country.

INDIANA'S COUNTY ROAD NETWORK

Indiana's local road network totals 80 163 miles. Of this total, 66 413 miles are the responsibility of county government. The remaining 13 751 miles of local roads fall under the jurisdiction of cities and towns. The basic county highway network is a grid, and its roads are typically spaced a mile apart. Designed principally for farm-to-market traffic, most of these roads retain their low-volume nature. Their surfaces range from gravel to paved, depending on actual volumes, vehicular loads, local maintenance philosophy, and available funds. About 55.5 percent of the highway county mileage is paved, whereas the rest is primarily gravel or stone surfaced.

Indiana has not been immune to the effects of increased highway maintenance costs and shrinking highway revenues. In recent years, the state has been hit hard by the combined ravages of unemployment, weather (snow, floods, tornadoes), and an assortment of new demands on local funds (upgrading sanitary landfills, relieving overcrowded jails, and so on).

FINANCING COUNTY ROADS IN INDIANA

As in other states, the state government in Indiana has the major responsibility of collecting and disbursing revenues for county highways. In FY 1981, $346 million in revenue was collected within the state for use on Indiana roads:

Revenue Source	Amount ($000 000s)
Fuel tax revenue	277
Other net revenue	64

Allocation	Amount ($000 000s)
State	177
Counties	106
Cities and towns	58
Distressed-road fund	5

These funds were distributed for state, county, and city and town use in accordance with the flow chart shown in Figure 1.

Anticipating continued increases in highway maintenance costs and expecting no significant rise in the amount of automobile fuel purchased, the state legislature recently enacted one of the nation's first ad valorem gasoline taxes. However, the legislature, like everyone else, had expected fuel prices to continue their steady rise. The gasoline glut of 1982 reversed this trend, along with the path of projected highway revenues. As it was, the director of Indiana's Department of Highways (IDOH) announced in May that FY 1983 motor fuel tax revenues would be about $47 million less than was projected one year earlier. This, coupled with a winter snow and ice removal budget that was exceeded by several million dollars last winter, meant that (3) there simply would not be enough money to cover all of the planned work and the emergencies, too. Thus, the state was not likely to be a ready source of funds to supplement local highway budgets.

As the revenue pie shared by state and local highway agencies shrinks in relation to the expense shown in maintaining roads and bridges, the concern each local agency feels about receiving its fair share of those revenues intensifies. The allocation scheme shown in Figure 1 represents a reasonable approach, but any such mechanism is vulnerable to complaints--always sincere and often legitimate--about its equity. The scheme relies on these factors: population, vehicle registration, and road mileage within each jurisdiction. The data in Table 1 demonstrate the problems that result from such a procedure.

An official responsible for maintaining the county roads in Benton County can check the summary of revenue allocations and find that although the rural roads in Lake County are approximately the same in extent, the Lake County official has almost five times as much money to use. When the revenues of the cities and towns are included, the countywide ratio of dollars per mile becomes even more disparate. However, Lake County can use the same data to advance a complaint of its own. People own and operate vehicles, vehicles cause the deterioration of streets and highways, and Lake County has many more of both than Benton County. Yet Lake County as a whole receives only half as much per vehicle as does Benton County. A rural county seeks to maintain its basic road network, whereas an urban county attempts to keep pace with the destructive effects of high traffic densities. Both feel shortchanged, but neither is likely to find a remedy at the statehouse. Any proposed revision is likely to hurt as many jurisdictions as it would help, and a large enough number of jurisdictions would be sufficiently

Figure 1. Distribution of motor fuel tax revenues.

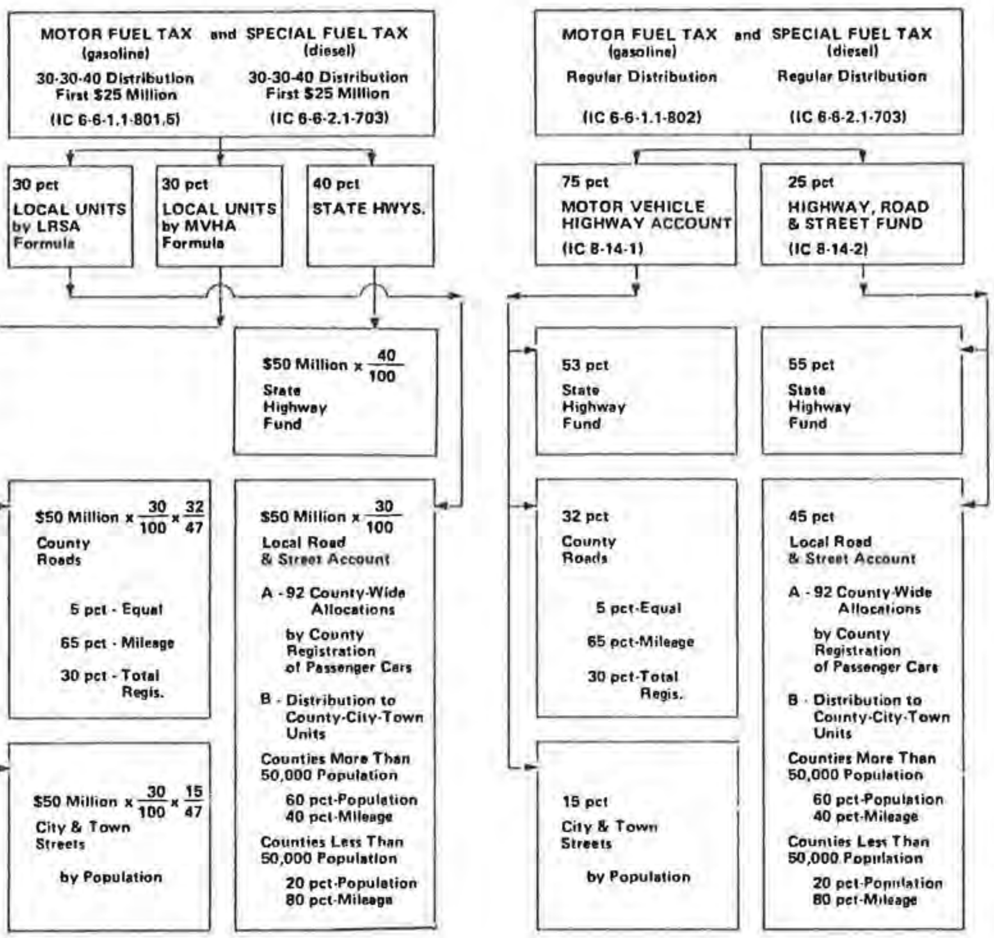

Table 1. Comparison of county highway allocations.

County and Jurisdiction	1980 Population	1980 Vehicle Registration	1981 Miles	FY 1981 Allocation: Amount ($000s)	Dollars per Person	Dollars per Vehicle	Dollars per Mile
Benton County							
Rural roads	3 901	N/A	673	740	190	N/A	1100
All roads	10 218	10 864	726	834	82	77	1149
Lake County							
Rural roads	41 870	N/A	625	3 472	83	NA	5555
All roads	552 965	357 721	2197	13 687	26	38	6230

unaffected to prevent a majority supporting change from forming. Besides, two more obvious--but not painless--alternatives already exist. The first is a further increase in the state motor fuel tax. The second involves local options that will be discussed in the next section.

COUNTY LOCAL-OPTION TAXES

As highway maintenance costs escalate, traditional highway revenues are diminished, and the allocation equity debate becomes more futile, interest in an option available to the counties is beginning to grow. The current option is twofold: an excise surtax and a wheel tax (4).

The 1980 Indiana legislature provided the state's counties with a statutory procedure whereby they can, at their own discretion, generate additional revenues to upgrade the conditions of the local road and street systems under their jurisdiction. The excise surtax is a surtax on the annual excise tax paid on passenger cars, trucks of less than 11 000 lb gross vehicle weight, and motorcycles registered in a county. Public Law 10 (1980) authorized an annual excise surtax of not less than 2 percent or more than 10 percent to be paid with the annual registration of the affected motor vehicles. The surtax must be uniform on all classifications of motor vehicles subject to the excise tax.

The wheel tax is not a tax on the number of wheels or axles but an annual tax paid on six classifications of motor vehicles registered in the county that are not subject to an excise tax. PL 10 authorizes an annual wheel tax of not less than $5 or more than $40 to be paid with the annual registration fees. A county may impose a different tax for each of six motor vehicle classes: buses, recreational vehicles, semitrailers, tractors, trailers, and trucks. Wheel-tax exemptions include vehicles owned by a public agency, church buses, and vehicles subject to the annual excise surtax.

This new home-rule authority for county government provides a mechanism for dealing with the wide variations in local needs for roads and streets over the state. In making the decision to impose these local-option taxes, local officials should weigh the road and street needs in their county against their ability to meet these needs with state-distributed revenues. Both of these local-option taxes must be imposed at the same time. Likewise, if removed, both taxes must be removed simultaneously. The revenue derived from these taxes must be distributed to the county-city-town units within the county solely on the basis of road and street mileage in each jurisdiction.

Returning to the case of Table 1, we can estimate the impact of such taxes in Benton and Lake Counties. At their maximum levels, the taxes can increase highway revenues available for local use by the amounts shown below:

County and Jurisdiction	Maximum Local-Option Tax Revenues ($000s)	Increase Over 1981 Revenues (%)
Benton County		
Rural roads	136.6	18.5
All roads	147.5	17.7
Lake County		
Rural roads	860.0	24.8
All roads	3024.3	22.1

These taxes are collected on a vehicle basis but distributed on a road-mile basis within the county that enacts them. Although this blend of philosophies might lessen the equity question raised earlier, it appears that Lake County may have more to gain from such a tax.

As appealing as the home-rule argument might be to local officials weary of dependence on a state-level allocation mechanism, the local-option taxes have not been widely adopted. Even among the 10 Indiana counties offered interest-free loans from the Distressed-Road Fund if they first adopt the local-option taxes, only two have adopted the measures. PL 10 requires that the excise surtax and wheel tax be adopted at least six months before the start of a calendar year. As July 1, 1982, approached, Indiana saw a number of counties address the issue. However, the results were mostly negative. In fact, of Indiana's 92 counties, only 8 have adopted the measures. The arguments against passage seem to have focused on questions of revenue-generation potential, equity, state-county relations, and the use of revenues generated.

A common complaint of county council members is that the current local-option tax provision does not allow for generation of enough revenue to justify the political cost of raising a local tax. As of January 1983, new legislation had been introduced to increase the revenue potential of the excise surtax portion about eightfold.

An example of the equity question is the inflexibility of certain wheel-tax provisions. Whereas the excise surtax is tied to a vehicle's value, the wheel tax makes no distinction within its six vehicle classes, in which a large variation in size and value may occur. The newly proposed law will allow counties to set different rates within the trailer and truck categories.

At a time when local governments are looking to the state to ease the transition from federal revenue-sharing to a possible future under New Federalism, local officials are reluctant to use up any revenue-generating sources. "If we raise the $90 000 this year," one county council president remarked, "next year they'll say, 'OK, now get $180 000'" (5).

Inequality in the use of revenues generated locally was raised by another county council member (6): "If we raise $90 000, that would blacktop about two miles of road. What do we tell the guy who pays $40 per truck for his three trucks and still doesn't get his road fixed?"

Statements such as these illustrate the other side of the home-rule coin. They also demonstrate the change in thinking that must come about when local governments assume--by choice or necessity--a greater role in revenue raising and allocation. If that $90 000 mentioned above were in the form of a federal grant, would the decision as to its use be any different? Would the truck owner consider it as much a personal tax as the wheel tax? Will methods for setting priorities for public projects become more rigorous as citizens begin to identify more closely with tax revenues and their use? Local control and user fees both seem to be gaining favor as political ideals. The local-option taxes available in Indiana are examples of how these elements can be combined. The degree to which they (and similar measures) are accepted will indicate the future not only of local roads and streets but of a wide variety of services that have been locally provided but reliant on external funding.

BRIDGE AT AMERICUS

In this section and the next, two cases are presented that illustrate the types of situations that confront citizens and their local officials in the realm of basic transportation. In this section, the problem is that of a needed major capital project and its impact on both the county budget and a small town's economic well-being. In the next section, a relatively minor project was nevertheless important enough to some citizens to rouse a new spirit of citizen initiative in what is typically public-sector activity. Although quite different in scope and consequence, both cases serve to exemplify the increasingly difficult problem faced by local agencies responsible for roads and streets: how to establish priorities and evaluate the impacts of allocating very limited funds when only a few of many justified projects can be carried out.

Americus, Indiana, is an unincorporated town of about 100 persons situated along the Wabash River. State Route 25 passes through Americus and connects Lafayette (the county seat with population 43 000 about 11 miles to the south) and Delphi (3000 people, about 6 miles north of Americus). East-west traffic through Americus is predominantly local in nature. To the southeast is a limited network of county roads serving rural and agricultural properties. To the west is County Bridge 150, which connects Americus with sparsely populated sections of northern Tippecanoe County.

Late in May 1982, the county commissioners, acting on the advice of the county engineer and a private consultant, ordered bridge 150 across the Wabash at Americus closed. The engineer cited holes in the bridge deck and a 1979 inspection that revealed that all of the joints in the structure, built in 1893, were frozen. Residents in the area objected to this action on several counts:

1. Closing the county bridge would add a 14-mile detour around Americus to trips on SR 25. The six small businesses in Americus could not survive even a small drop in patronage caused by such a detour.
2. On June 14, 1982, bridge 144 on SR 25, the main link to Lafayette, was scheduled to be closed by state officials for 100 days for reconstruction.
3. The state's closing of SR 25 carried with it an official state-designated detour of about 22 miles. A much shorter detour involved using county roads to the southeast of Americus and through Buck Creek before rejoining SR 25. But these roads have hazardous spots with steep hills and narrow bridges. If a significant fraction of SR 25's normal 6000 vehicles per day used these county roads as a detour, county officials might be facing still another highway maintenance problem.
4. The next bridge north of Americus across the Wabash had been closed for reconstruction for more than a year. The net result for Americus would be virtual isolation from customers, important services, and the nearest cities.

On June 8, 1982, the Tippecanoe County Council approved expenditures in excess of $500 000 for bridge and road repair in the county. Three other bridges and two road sections were to receive attention, but the Americus bridge project was too big for the county to undertake alone.

On June 21, 1982, the County Council announced that the bridge would remain closed but that the county commissioners would seek funds on both the county and federal levels to replace the bridge. County officials had completed engineering plans to replace the bridge, but those plans were shelved until about early May. The officials had been told that the state planned to replace the SR 225 bridge over the Wabash--the next bridge south of the Americus bridge. This might have made reconstruction at Americus unnecessary or at least postponable. Now it appears that the SR 225 bridge will not be rebuilt until 1986 at the earliest. On March 1, 1982, the commissioners had decided to use federal funds in FY 1983 for work on County Road 900-E and the Granville bridge. On June 21, they approved sending in federal forms that requested a transfer of funds from County Road 900-E to the Americus bridge project. Finally, in January 1983, $1.1 million in federal funds was earmarked to help pay for replacing the Americus bridge, a project estimated to cost more than $1.5 million. The county's share will be approximately $300 000.

The Americus bridge controversy typifies the difficult problem of setting priorities among competing projects. It underscores the dilemma that local officials will face with increasing frequency if funds become less available. In addition, the incident produced an interesting aspect of citizen participation in highway development. During one of the meetings between residents of Americus and county officials, a commissioner offered an unusual suggestion. She suggested that the citizens hire their own engineering firm to verify the original study done for the county. If the firm determined that safe use could be made of the bridge, that firm should also assume liability for any resulting mishaps. This suggestion is a step beyond what is usually meant by citizen participation, but it is not without precedent, as the next section will demonstrate.

BOONE COUNTY ROAD 200-S

Nine families who live along a 0.7-mile segment of County Road 200-S near Lebanon, Indiana, have taken the term "citizen initiative" seriously. Located immediately off US-421, the crevasses, trenches, and craters of this stretch known as Old Mud Road have wrought havoc with cars attempting to negotiate its length. Residents speak of demolished mufflers, ruined paint jobs, short-lived shocks, and frequent front-end alignments. The problem is exacerbated by the area's high water table. Water springs up in the road and flows in the holes and trenches of the roadway. Heavy rains make it even worse. And when it does not rain, the dust from passing traffic is a severe problem.

Recognizing that Boone County could not in the foreseeable future put County Road 200-S ahead of other road and bridge projects in the line-up for funding, the families there are raising $10 000 to upgrade "their" road. The nine families whose homes are east of bridge 196 over Fendley Creek represent a variety of income levels, and the financial contribution from each household varies accordingly (7).

Mike Owen was the resident chosen to seek bids on the project. He understood that the county would, in August, reform the ditches and prepare the roadbed by scarifying, combining, and compacting before the contractor's arrival. The best bid received to date--$10 500--includes the cost of stone, liquid asphalt, and sealant for a 20-ft roadway width. The county has offered to haul stone for the contractor. The resulting chip-and-seal surface is expected to provide a much-improved level of service while it keeps maintenance costs modest. The county has pledged to reseal the surface on a 2- to 5-year cycle.

Several factors led the families on 200-S to their present course:

1. Bridge 189 on County Road 300-S (which parallels 200-S) is scheduled for temporary closing in the near future. The additional traffic that uses 200-S as a detour would only intensify the road's current inadequacies.
2. In 1982, residents of a subdivision along 975-E hired their own contractor to improve their road. Due to the larger number of families in-

volved, the double-chip-and-seal surface was successfully achieved at about $300 per household. The county performed the ditch work and surface preparation before the contractor's arrival and will perform maintenance on the road every two years.

3. Another 200-S resident, Dot Chapel, said that government participation in the funding of the road improvement project did not appear practical. Besides the inevitable red tape and uncertain results that accompany a government program, stringent standards would apply. This would mean that bridge 196 would have to be upgraded, which would cause considerable added expense and a lengthy closing of the road they sought to improve.

4. The choice of road surface was based on observations in a number of counties. Owen detected regret on the part of officials in those counties where a large-scale paving program had taken place in recent years. The maintenance costs were becoming intolerable. On the other hand, Chapel cited Kosciusko County, where all the roads are chip and seal. The surfaces are maintained in good condition at reasonable cost.

During personal interviews with the principals in this project, at no time was any animosity or resentment between residents and county officials detected. Boone County Commissioner Sam E. Dodd regrets the lack of money for such work but says that self-financing "is the only way it's going to get done. I told the people that if they agree to do it, we'll grade it and do the ditches because we have the equipment for that. Ultimately, it will become a good road if there's not too much heavy traffic on it" (7).

Commissioner Dodd said that 60 percent of Boone County's 840 miles of roads was gravel. The county's small population (36 000) limits its ability to generate significant additional revenues locally. When asked about the local-option taxes, which could generate up to $300 000 for the county, Dodd raised yet another aspect of the equity issue discussed earlier in this paper. How could he propose and pass a new tax on the vehicle registration and license process when so much of the existing fees so collected go for nonhighway activities?

Dodd has a point. The vehicle excise tax, payable at license renewal time and the basis for the excise tax surcharge element of the local option, is collected by the motor vehicle license branch in each county. According to Indiana's deputy commissioner of the Bureau of Motor Vehicles (BMV), these tax revenues are deposited locally to an account held jointly by the BMV and the county treasurer. The county treasurer can, twice a year, apply these revenues to the needs of the county. And these needs are many. The diversion of these revenues to support activities such as fire protection, parks, and education often leaves little or nothing for highway-related use. Local property taxes in Indiana have been frozen for several years, and competition for any funds not earmarked is intense. The appeal of user fees is in conflict with the realities of entitlements, transfer payments, and application of revenues raised in one sector applied to totally unrelated activities. This leaves citizens, especially those in Indiana who pride themselves on local initiative and self-reliance, unreceptive to new taxes as a remedy. The citizen involvement exemplified by the families along Boone County Road 200-S may become the model for future local road improvements.

CONCLUSIONS

The Americus and Boone County examples presented in this paper indicate the sort of mechanisms that may emerge as highway revenues fail to keep pace with highway needs.

The bridge closings at Americus highlight the difficulty that local officials face in making a tradeoff among highway projects within their jurisdiction. The case also illustrates the relationship of a county government to its citizens and the importance of effective coordination with higher levels of government in today's fiscal climate.

Although the nature and magnitude of the Americus bridge situation required working entirely within the governmental process, the citizens on Boone County Road 200-S were able to form a sort of partnership with their county officials. By financing the cost of materials that the county budget could not afford, the residents will acquire a dust-free road and provide all traffic a much higher level of service. The county's principal contribution will be personnel and equipment, resources that are already in the budget. For only a small amount of direct cost, such as fuel, Boone County achieves a marked improvement in part of its road network.

It may be worthwhile to examine a possible objection to the Boone County procedure. It could be said that if this practice were to proliferate, only those roads for which residents are willing and able to pay for materials will be in good condition. But this argument seems to

1. Forget that county roads are public goods available to any driver. The more widespread citizen financing becomes, the greater the number of nonpaying beneficiaries there will be.

2. Ignore the fact that citizen-financed roads can be upgraded at negligible cost to county taxpayers, whereas the considerable savings in maintenance costs that result can be applied to other county highway needs.

3. Assume that so many neighborhood groups will be willing to pay sums well in excess of their existing county taxes that established ways of programming highway funds will be abandoned and the county highway budget will be allowed to shrink to imprudently low levels.

4. Assume that the elected county officials who establish funding levels and priorities are not sensitive to the wishes of their voting constituencies.

The decision of a neighborhood group to contribute thousands of dollars to what has been exclusively a government function is primarily an economic one. The project must meet the approval of county officials whether or not county resources are sought. It is here that the political counterweight in the interests of the general public's welfare can be applied.

It is not certain to what extent, if any, the New Federalism proposals will be enacted. One year after his original suggestions, President Reagan scaled down his plan to transfer federal programs to state and local governments. Objection has come from almost every group that receives federal money. A survey by the National League of Cities found that most cities have been unable or unwilling to replace lost federal aid from their own revenues. Five thousand delegates at a July 1982 meeting of the National Association of Counties challenged basic features of the Reagan plan and insisted that all welfare be handed over to the federal government and that direct grants to localities be continued instead of turned over to the states. The American Public Transit Association condemns the reduction of federal aid to transit as incompatible with attempts to revitalize the economy.

For many years, if average citizens knew the name of any of their legislators, it was their senator or U.S. representative. City council members and elected county officials labored under virtual anonymity. Recently, we have seen evidence of a reversal in this situation. The Americus bridge project and the local-option tax examples should serve as warnings to state and local officials about the possible not-so-distant future of highway funding. It is appropriate and expected that local citizens have a keen interest in how local funds are spent and in how local projects are selected. But as major projects become even more expensive, a new mechanism for funding large local projects must be developed. Most of Indiana's localities have populations and tax bases that cannot measure up to an individual large road or bridge project, let alone a number of them over a period of a few years.

It is with these large projects that new fund-allocation procedures and renewed efforts at interjurisdictional cooperation are critical. Among the measures that demand sober, unselfish evaluation are

1. The feasibility of levying special-assessment fees for highway improvement and maintenance for property owners adjacent to the rights-of-way (this option is particularly relevant for county roads, most of which are farm-to-market roads); special assessment will thus reflect direct-user fees;
2. A practical mechanism for localities to accumulate funds for planned or emergency future projects;
3. The establishment of a state-level capital fund for large projects on local roads; grants could be made on project merit, a rotational basis, or other criteria;
4. A streamlined and equitable method for reevaluating the appropriate jurisdiction for a given road together with appropriate standards for its design and upkeep; and
5. The removal of obstacles to the cooperation of different jurisdictions in undertaking a mutually beneficial project.

If any significant portions of the New Federalism proposals survive the political battlefield, an era of opportunity and hard choices lies ahead. No longer will the major concern be effective grantsmanship at the federal level. Instead, we will have a clearer recognition that it is our money being spent. Citizen input will be more direct and intense, both to spend and not to spend. Local officials will be pressed to offer solid justification for their use of tax revenues. And local taxes may rise, even significantly. But if local tax increases occur in response to public demand for services, if measures such as the five listed in the previous paragraph can be implemented, and if at the same time the federal and state tax burdens can be eased, progress will have been made. If we can achieve progress in the category of postponable highway maintenance, we will surely see improvements in other areas.

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Current Trends in Toll Financing

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User fees for the consumption of services provided by transportation facilities have been accepted for centuries and are receiving wider support today for future application. Currently in the United States, 28 states operate 36 toll roads and 43 toll bridges. In addition, 29 county and 27 municipal toll facilities, primarily bridges, are now in operation across the country. Despite the effects of the 1956 Federal-Aid Highway Act, which discouraged the user-fee concept for highways, 20 new toll roads totaling 770 miles and 13 new toll bridges have become operational in the United States during the last 15 years. The toll concept has also become accepted internationally; France, Spain, Italy, Japan, and Britain are among the many nations operating successful toll facilities. Toll projects, especially toll roads, are gaining approval for several reasons. First, user fees can partly relieve the state governments of the financial burden of providing adequate and efficient highways. Second, toll facilities often provide better emergency and patrol services and a greater degree of safety than their nontoll counterparts. Last, through rate differentials, toll roads can encourage carpooling, thereby maximizing energy efficiency, or can offer special commuter rates for frequent users. Creative financing has become the key to expansion of the present toll-facilities system. Traditionally, financing has been accomplished with the use of revenue bonds when costs incurred in the construction and operation of toll facilities are covered completely by toll revenues. In 1965, the Dallas North Tollway was the last major new toll road to be financed with revenue bonds; the financing since then has been extensions of existing systems or included subsidies and/or pledges of other than toll income. The Ambassador Bridge in Detroit, privately financed and operated by the Detroit International Bridge Company, is one of the few major toll facilities still in private ownership. Future expansion of the toll concept depends heavily on actions of the federal and state governments as to possible use of federal funds to partly defray the construction cost of new toll facilities as well as on the extent to which federal contributions can be made to annual maintenance and rehabilitation costs. It is expected, too, that greater public-

and private-sector cooperation will play a vital role in the future of toll-facility financing.

Charging a fee for the use of a highway, bridge, tunnel, or ferry is not a new idea. There is historical evidence that such facilities existed before the birth of Christ, for example, the toll road from Syria to Babylon. In England, toll concepts date back to the 12th century. By 1281, tolls were applied to the old London Bridge and, interestingly, also to ships passing underneath the structure. By 1820, Britain had 20 000 miles of toll roads in operation.

Many of the earliest rural roads in the United States and early crossings of major rivers were tolled. At that time, funds for the construction and maintenance of roads from public tax sources were almost nil. In 1785, the Legislature of Virginia enacted a law providing for the erection of turnpikes on roads. Most highway professionals are familiar with the 62-mile Lancaster Pike, completed in Pennsylvania in 1794. It contained 13 toll gates and was the first of its type to have a variable toll schedule related to the number of axles on vehicles and the number of horses used.

As one looks at the history of toll roads, it appears that these roads have had cyclic patterns, especially in the United States. Some of the first roads along the Eastern seaboard were constructed as toll facilities. This trend continued into the first two decades of this century. Early county and state road systems often contained toll bridges or ferries, which were in some cases privately owned and operated. Then, when road building was more formally organized and administered, by the formation of state highway organizations and the creation of the U.S. Bureau of Public Roads, an antitoll attitude developed, and most of the existing toll facilities were made free facilities. In some cases, this was done by adding a county road on which the facility was located to the state highway system; in other cases, the county or state purchased all rights to private toll facilities.

The modern era of U.S. tollways began in the 1930s, engendered largely by the rapid increases in vehicular traffic in major corridors. With the passage of the Federal-Aid Highway Act of 1956, which accelerated authorization of funds for the Interstate system, a decline began in the toll roads.

Now, for almost a decade, the country has witnessed an upturn in popularity of toll highway facilities. Since 1968, 20 new toll roads totaling 769.76 miles and 13 new toll bridges have become operational in the United States (1,2). For many years, study results have been available that indicate that on some toll facilities up to 15 percent of the users might be driving farther, taking more time, and paying more tolls than would be required to make the same trip on free facilities. Current interest in toll roads likely relates to the energy crisis, environmental and other regulations that substantially increased the costs of facilities, reductions in travel, fuel-efficient vehicles, and inflation as related to capital maintenance and operating costs of highway systems; in short, the same amount of money today buys less than it did in the past. There is no evidence that the trend is diminishing; there is more intense interest now in toll financing than 10 years ago.

In a brief overview of past and current sources of revenues to fund highway transit improvements and innovations being considered, it is important to place the trend in toll financing in proper perspective. Certainly much is known and has been said about the deterioration of the nation's highway and bridge system. According to a study by The Road Information Program (TRIP), 60 percent of the country's 2 million miles of paved roadway needs resurfacing or rebuilding (3). The estimated cost of repairing these roadways is $270 billion. In comparison, both federal and state spending last year totaled $19.2 billion.

On January 6, 1983, President Reagan signed a measure to raise the current 4-cent federal motor fuel tax by 5 cents; 80 percent of the funds, or approximately $52 billion per year, was earmarked for highway purposes and the remainder for mass transit. Under this Surface Transportation Assistance Act of 1982, more than half of the highway funds will be allocated for Interstate construction, Interstate 4R work, and bridge replacement-rehabilitation.

Under the new measure, there are emergency provisions whereby state matching funds can be deferred in 1983 and 1984. The means by which to generate these matching funds are of concern to a number of states.

THE FISCAL DILEMMA

Across the country, the average gasoline tax per gallon has risen 10 cents, with differentials on diesel fuel, as motor fuel sales have stabilized (3,4). In some states such as Iowa, gasohol is exempt from state tax. Most state departments of transportation have made severe budget cuts, forcing cutbacks in expenditures and services.

In April 1982, nine states were considering increases in gasoline taxes (4). Twelve states, including the District of Columbia, Indiana, Kentucky, Massachusetts, Michigan, Nebraska, New Mexico, Ohio, Pennsylvania, Rhode Island, Virginia, and Washington, have introduced variable motor fuel taxes--the tax is a percentage of the sale rather than a fixed rate per gallon. Of the nine states that now collect a sales tax on motor fuel, only two dedicate the funds received to transportation improvements. Other states are considering adding motor fuel to the list of items covered by sales tax, including Connecticut, which would impose a 7.5 percent sales tax on motor fuel. Another bill in the Connecticut legislature would introduce a special sales tax on gasoline equal to 12 percent of the sales price (4).

Many other forms of increased taxation are being considered by the various states, all of which would raise the cost to the user. They include a variety of levies--vehicle registration fees; excise taxes on automobile sales, parts, accessories, and repairs; special truck taxes such as gross receipts, fuel surcharge, axle-mile, ton-mile, mileage, and weight-distance; fees for driver's license and certificate of title; tax on lubricating oils; and increases in current allocations of funds for transportation improvements from such sources as expansion of the base for sales tax and various other forms of taxes such as liquor, tobacco, and income. In Kentucky and Utah, income is derived from state energy road taxes and in Pennsylvania, Virginia, and Rhode Island from oil franchise taxes (4).

While a substantial part of the funds for highway-bridge system maintenance and improvements is derived from federal and state taxes, county and regional-based taxes also contribute. At the county and municipal levels, ad valorem taxes in large measure fund maintenance of the local road systems, with support from the state. The cost of constructing new residential streets is often the responsibility of the developer, an important example of the role of private industry in development of the local infrastructure.

The use of the private sector and end user to meet maintenance and improvement needs rather than reliance on government subsidies is becoming increasingly popular in other transportation modes. General aviation's fuel tax and scheduled airlines waybill and passenger taxes are good examples. Many airports are also considering introduction of an access tax such as that now assessed at Dallas-Ft. Worth Airport as a means of increasing revenues. Lock fees coupled with fuel taxes are under serious scrutiny as a means to reduce government subsidy of waterborne commerce. Gross volume taxes were imposed at one time on pipelines, and ton-mile taxes on highway-transported commerce have long been debated.

Creative financing and identity of funding sources is the central theme today; all levels of government realize that fewer federal dollars are available and less will be provided in the future. Although the provisions of the Surface Transportation Assistance Act of 1982 seem to fly in the face of this statement, it should be remembered that the billions in federal funds to be allocated over the next four fiscal years is only a small portion of the total needed to bring the highway system up to acceptable condition. Even if the states were to somehow come together and all increase state motor fuel taxes by the same 5 cents and, as important, dedicate all such income to highway improvements, the impact would still be far below the revenue level needed.

MASS TRANSIT FINANCING INITIATIVES

Mass transit, which will also benefit under the Surface Transportation Assistance Act of 1982, has been far more innovative in seeking to obtain funds from other than traditional sources. Such sources have ranged from a state lottery in Arizona to revenue bond issues in New York City and San Francisco, California, backed not only by transit patron fares but also by vehicle tolls collected on bridges and tunnels. The bonding by the Metropolitan Transportation Authority (MTA) in New York City has local government backing and the $250 million bond series sold in October will go toward the purchase of new railcars; no federal funds will be involved in the purchase (5).

Using vehicle tolls to support mass transit is not a new concept. The Golden Gate Bridge Authority has subsidized not only a rubber-tired transit system but also a commuter ferry service for several years. A significant portion of the Bay Area Rapid Transit (BART) connection under Oakland Bay was financed by vehicle tolls collected on the Oakland Bay bridges together with a special property tax in the three counties it serves plus federal and state funds (6).

In addition to transit patron fares, the BART system in San Francisco receives operating funds from a special sales tax in San Francisco, Alameda, and Contra Costa Counties and a percentage of the statewide sales tax revenues collected. BART recently issued $65 million in bonds for capital needs, backed by patron fares and the annual income derived from the sales taxes dedicated to transit.

In Houston, Texas, a 1 percent regional sales tax is programmed to provide the main support for an 18-mile heavy commuter rail system; currently implementation will not involve any use of federal funds. The Metropolitan Transit Authority of Harris County receives the 1 percent sales tax collected on sales in the City of Houston and part of Harris and Montgomery Counties. Sales tax proceeds accounted for 67 percent of Harris County transit authority's 1981 total revenue.

The Metropolitan Atlanta Rapid Transit Authority (MARTA) system is also partly funded by a regional sales tax. A 1 percent sales tax is levied in Fulton and DeKalb Counties of which 99 percent is dedicated to MARTA. The remaining 1 percent goes to the state of Georgia.

Los Angeles County has a 1/2-cent sales tax projected to raise $290 million per year in support of mass transit. In addition, 25 percent of the 6 percent state sales tax collected in the county is returned and dedicated to transit. Of this amount, the Southern California Rapid Transit District receives 87 percent (6, p. C-3).

Elsewhere, Birmingham, Alabama, plans to use a tax on beer to raise $2 million annually to support mass transit. Since January 1981, 24 transit systems now operate with some form of dedicated tax.

ALTERNATIVE METHODS OF HIGHWAY FINANCING

Certainly it is expected that the traditional methods of raising funds for highway maintenance and improvements will remain viable, but there is also no doubt that these sources will have to be bolstered by other means to maintain the integrity of the nation's highway-bridge infrastructure. Recently, the concept of leveraging annual state income derived from these traditional revenue sources through issuance of revenue bonds has become more pronounced.

Today, 28 states operate 36 toll road systems and 43 toll bridge systems. In addition, 29 county and 27 municipal toll facilities, primarily bridges, are now in operation across the country (7, Table SF-3B). Summarized by intrastate versus interstate facilities and including toll ferry services, there are 68 intrastate toll roads, 83 bridges, 76 ferries, and 7 tunnels. In addition, there are 58 interstate toll bridges, 29 ferries, and 2 tunnels (8).

The Federal-Aid Road Act of 1916 for the first time in history made federal funds available to the states as assistance in providing roads. A major stipulation of the act was the prohibition of tolls of any kind. The Federal Highway Act of 1921 reemphasized this point. Interestingly, however, the Pennsylvania Turnpike, the first modern toll road, was built with federal assistance in 1940. Between 1940 and 1956, toll roads in the United States proliferated. The sudden expansion of toll roads largely ended, however, with the 1956 Federal-Aid Highway Act. That act provided for 90 percent federal financing of the Interstate system; a substantial increase in federal funds available for highway networks; inclusion of toll roads, bridges, and tunnels in the Interstate system where the facilities met Interstate standards; and the use of federal funds for approaches to toll roads.

There have been, however, several enforcement problems that have prevented complete implementation of the 1956 highway act. One hindrance to the act concerns the ability of the states to repay federal-aid funds in order to make the road, bridge, or tunnel into a toll facility. For example, the 1954 Federal-Aid Highway Act allowed Connecticut to repay federal funds in order to build part of the Connecticut Turnpike as a toll facility. Again, in 1960, the Federal-Aid Highway Act permitted Delaware and Maryland to repay federal funds used to construct I-95; each state tolled their portion of I-95. New Jersey has also repaid federal funds in order to toll portions of the Garden State Parkway.

There is a further hindrance to the federal government's efforts to have totally toll-free Interstate and primary systems. The Oldfield Act of 1927 permitted federal-aid funds to be used in the construction of toll bridges and approaches. Adopted as Section 129 of Title 23 of the United States Code, the law (9, p. 6)

> permits federal participation in toll bridges, toll tunnels, and approaches thereto; toll road approaches to the Interstate System; and upgrading of two-lane toll roads to Interstate System standards. To receive federal funds, the states must agree to make the toll facilities free to public travel upon collection of tolls sufficient to retire the indebtedness of these facilities.

The effort made by Section 129 to make all roads toll free has been thwarted. Both Maine and Indiana, states that once had Section 129 agreements, have attained congressional relief and have paid back federal-aid funds in order to retain revenue-producing tolls on their respective facilities.

A major roadblock in the way of converting toll facilities to tax-supported facilities is the current lack of a federal plan to reimburse the states' costs of building toll facilities or to cover the states' current indebtedness to the respective bond holders.

The benefits of toll facilities are many. Not only do toll facilities provide fiscal relief to the state from the burden of maintaining, operating, and reconstructing highway facilities, but they serve the motoring public and taxpayer in general. Toll facilities have the ability to match the cost of using such a facility with the benefits derived by each class of user. Separate toll classes are maintained for each vehicle class.

Also, users pay for the facility, which lessens the financial burden on the taxpayer. Furthermore, toll rates can be charged to affect traffic flow, thereby smoothing movements during peak periods, and to encourage energy conservation by charging a separate ridesharing trip toll. In addition, toll facilities normally offer a greater degree of highway policing; a higher level of safety; on-the-road facilities, such as motor fuel stations and restaurants; and emergency highway services. Last, in the event that sufficient federal funds are not available for the construction of a travel facility in an area with a growing travel need, the toll-facility concept offers an effective alternative.

The three basic approaches to toll financing used to date are revenue bonds, revenue bonds supplemented by income other than that paid by users, and private financing. The first two are variations of public or quasi-public operations and the last of entrepreneurial operations.

The Ambassador Bridge in Detroit, Michigan, privately financed and operated by the Detroit International Bridge Company, is one of the few major toll facilities still in private ownership. Beginning with the Connecticut Department of Transportation's financing of the Merritt Parkway, several state highway departments have issued bonds supported by tolls generated by proposed toll facilities but, importantly, also backed by income generated by state highway taxes, total state income, or combinations thereof.

In some instances, the tax monies served simply as a pledge and were never drawn on. Most of the trust instruments call for repayment of any tax funds advanced prior to removal of tolls. Among the states employing this general concept, in addition to Connecticut, are New Hampshire, Virginia, Iowa, Louisiana, Maryland, Alaska, Delaware, Oregon, Florida, Indiana, and Kentucky (7).

Variations of state involvement are also in place in other states. The Kentucky arrangement calls for the turnpike authority to issue sufficient bonds for project construction; the authority then enters into a two-year, renewable lease agreement with the Kentucky Department of Transportation to maintain, operate, and provide all project debt service.

In Oklahoma, the turnpike authority operates the Will Rogers Turnpike and the Oklahoma Turnpike System; the latter is made up of five different projects. Shortly, the original debt on the Will Rogers Turnpike will be retired, and it too will become a part of the system. Based on a miles-per-gallon formula for various types of vehicles, the state motor fuel tax represented by the vehicle miles of travel on the turnpike system is credited annually to an account managed by the authority from which funds can be drawn to meet project debt service requirements.

In Florida, the turnpike was financed through issuance of revenue bonds and most all other toll facilities through bonds marketed by the state department of transportation that carried the pledge of the uncommitted portion of annual state motor fuel tax receipts allocated to the county in which the facility is located. In addition, the department of transportation agrees to maintain and operate each such project and to reimburse these expenses after all initial bonded indebtedness is retired and prior to the project's becoming toll-free and thereafter maintained by tax resources. At least one such project has reached this goal.

At present, federal law envisions the removal of tolls through defeasance of outstanding bonds for projects carrying Interstate highway system designation. It is not too difficult to imagine the reaction of some of these state transportation agencies to the prospect of suddenly inheriting many miles of limited-access highways, much of which were approaching the initial design-year age, and the potential downstream maintenance-rehabilitation burden. Immediately, most began negotiations with the various toll agencies involved to ensure that sufficient rehabilitation work would be accomplished prior to complete debt retirement so that the facilities would be turned over to the states in good operating condition. In the case of Ohio, this will require close to a $1 billion improvement program, which will delay transfer of the Ohio Turnpike to the state by several years.

A similar situation exists with the Pennsylvania Turnpike; well over $1 billion in upgrading would be required to bring that facility close to current Interstate highway system design standards. A considerably smaller expenditure was estimated back in 1974 to bring the Dallas-Ft. Worth Turnpike closer to such standards; this included the addition of several new interchanges. However, the turnpike debt was subsequently fully retired and the facility was transferred to the Texas Department of Public Transportation and Highways at the end of 1975. Since then, because of lack of adequate tax funds, maintenance of the project has suffered and none of the interchanges planned for construction, if tolls had been continued, have been implemented nor are there prospects that any will be in the near future.

In 1979, the Indiana Toll Road Commission was rapidly retiring its original bonded indebtedness, and under the terms of a tripartite agreement executed between the Commission and state and federal government, the toll road would soon become a part of the state's limited-access highway system. The tripartite agreement was reached many years ago when federal 90-10 funds were received for part of the construction of three Interstate highway connections to the toll road. With the active support of the state department of highways, which was concerned about accepting the facility without certain improvements, including the addition of several new interchanges, and the almost $10 million/year in maintenance cost, the Toll Road Commission embarked on a program that culminated successfully on October 1, 1980, with the marketing of a $259.5 million bond issue (10).

In the process, legislative and congressional action was obtained to abrogate the tripartite agreement calling for the toll road to become toll-free on retirement of the initial debt, that debt was refunded, and design was initiated and funds established to defray the entire cost of the improvement program. In addition, through continuation of tolls for the new 30-year bond term, the anticipated annual maintenance burden on the department of highways was eliminated.

Coincidentally, as part of the legislative process, the Indiana Toll Road Commission was abolished and effective July 1, 1982, operation of the toll road became the responsibility of the Indiana Department of Highways. The facility continues to operate under a trust agreement by which all income derived from tolls and other sources must be used for operating-maintenance expenses and to meet debt requirements, including bond amortization.

During the course of the work leading to the bond sale, two Indiana legislators located in the toll road corridor sponsored separate public opinion polls on the desirability of retaining tolls on the facility. Faced with the prospect of insufficient tax dollars to fund the improvement program, citizens in both polls indicated overwhelming support for continuation of tolls to accomplish this objective.

In Connecticut, during 1982, almost the opposite occurred when opponents of a continuation of tolls on the Connecticut Turnpike were narrowly defeated. Their argument was that users of the turnpike, much of which is designated I-95, were being unfairly discriminated against in relation to users of toll-free I-91. Two factors were said to heavily influence the outcome: (a) the existence of the turnpike trust agreement with bondholders and (b) the approximately $16 million in excess toll revenues that annually flows into the state general fund (11). Interestingly, the last of the bonded indebtedness on the Merritt and Wilbur Cross Parkways in Connecticut was retired several years ago, and tolls remain in place; the income from tolls continues to flow to the general fund each year.

Early in 1982, in Maine, the turnpike authority and department of transportation reached a milestone agreement. With defeasance of the original turnpike bonds scheduled for mid-1982, the Maine legislature enacted provisions calling for repayment from turnpike income of the federal 90-10 contributions received many years ago toward construction of several Interstate highway connections to the turnpike, continuations of tolls during this period of repayment, and an annual contribution to the department of transportation of no less than $4.7 million annually from turnpike revenues.

The turnpike authority subsequently obtained congressional approval to repay the Federal Highway Administration (FHWA) and to continue tolls until such repayment was accomplished, which effectively terminated the original tripartite agreement. Short-term revenue bonds in the principal amount of $7.5 million were issued. In this manner, the Maine Turnpike Authority will remain in existence until the new debt is retired, tolls will remain in effect during this period, and the authority will contribute a minimum of $4.7 million annually to the department of transportation for funding of highway improvements in the turnpike corridor.

In July 1982, the New York State Thruway Authority, New York State Department of Transportation (NYSDOT), and FHWA entered into a tripartite agreement that appears to have brought FHWA close to greater recognition of the value, as a supplemental resource, of the toll concept. In the agreement, NYSDOT will begin to receive 100 percent of the annual federal funding now flowing to the state for Interstate highway system maintenance; previously, this percentage had been adjusted downward by the ratio of New York State Thruway mileage to total Interstate highway system miles in the state.

NYSDOT would act as a conduit only and pass these funds on to the Thruway authority for maintenance purposes. On its part, the authority agreed to remove tolls on the Thruway on retirement of the last of the currently outstanding bonded indebtedness, issue no new bonds except under a restrictive emergency covenant, and turn the Thruway over to NYSDOT after elimination of tolls.

This position of the agreement, particularly as it relates to the toll-free transition, is not unique and is common to numerous other agreements consummated with toll agencies since inception of the Interstate highway system. The unique section pertains to remedial measures of the authority and does not eliminate tolls. After repayment of the last of the outstanding bonds, the authority will have 90 days to convert the project to toll-free status. If this does not occur, the authority must immediately begin paying interest, with no provision for principal amortization, on the sum of all federal funds received since 1982. In some quarters, this arrangement has been viewed as simply providing an interest-free loan for many years, after which interest only will be required to service the debt in the future should the authority or state default in making the project toll-free.

Looking back, there have been numerous other examples of federal participation in toll facilities, all mandated through congressional action. These have included payment of 90-10 Interstate highway system program funds to widen two-lane sections of the West Virginia Turnpike to four lanes, similar funding of extensive rehabilitation of the Richmond-Petersburg Turnpike in Virginia, and reconstruction of the two-lane Alligator Alley toll road in Florida to four lanes in conjunction with I-75 designation. In each such instance, the original toll agency involved, the state (if it did not serve as the toll agency, as in the case of Alligator Alley), and FHWA executed a tripartite agreement requiring that complete retirement of all initial bonded indebtedness plus all newly issued debt be accomplished within the originally programmed debt-amortization schedule, after which time the project would become toll-free and thereafter maintained by the state with tax resources.

The last major new toll road successfully financed with revenue bonds was built in 1965--the Dallas North Tollway. At that time, $33 650 000 in bonds were sold, based solely on the anticipated toll income to be generated by the approximately 10-mile-long facility (12). As an indication of the change in economics of toll-road financing, in August 1982, the Texas Turnpike Authority issued $168 090 000 in revenue bonds to finance a less than 5-mile extension of the original project and to refund the $7 710 000 of the original issue still outstanding (13). Similarly, very few self-sustaining major new toll bridges have been constructed over the past decade; the last was the Houston Ship Channel Bridge, for which a revenue bond issue of $102 million was sold in July 1978.

Since 1965, such projects as the Phase II portion of the Tampa South Crosstown Expressway in Florida were constructed and opened to traffic and the Ft. McHenry Tunnel in Baltimore, Maryland, is scheduled to open in June 1985. However, the Tampa project has a pledge on Hillsborough County's portion of the state motor fuel tax, and the tunnel in Baltimore is being constructed as a part of a toll facilities system, financed through the toll resources of all system projects.

In New York City, the Triborough Bridge and Tunnel Authority has issued more than $800 million in new revenue bonds since 1980; the bulk of these funds was used to support mass transit. During the past several years, tolls on the authority's several facilities have been steadily raised to a current level of twice the earlier rates. Recently, the authority also provided financial guarantees to construction and operation of the new Convention Center, although this backing would come into play only if the state of New York declared bankruptcy.

In 1981, the authority generated $263.2 million in revenues, of which $64.2 million was expended for maintenance-operating expenses and $28.1 million for bond debt service. Of the net available, $170.9 million, the first $24.0 million went to the New York City Transit Authority and the remaining $146.9 million was divided equally between the MTA and the New York City Transit Authority.

In Jacksonville, Florida, a successful group of urban toll bridges has helped meet transportation needs of the city. However, the Jacksonville Transportation Authority maintains two separate operating accounts, one for the toll facilities and the second for mass transit. Despite repeated attempts, the funds are presently not comingled.

Looking back on the success or failure of toll facilities, the conclusion must be drawn that such projects have proven to be viable. Of the great number of projects financed during the modern-day toll era, only three major facilities have defaulted. Only the Chicago Skyway and the Chesapeake Bay Bridge-Tunnel remain in this condition. Only the Series C bonds of the Chesapeake Bay Bridge-Tunnel are in arrears on interest payments, and the project is to become current with interest requirements by 1985, thereby removing the default status (14).

FUTURE PROSPECTS FOR TOLL FINANCING

Even though they realize the difficulty of successfully financing revenue bond toll facilities under current market conditions, why are an increasing number of states considering use of the toll concept? The answer is simply that in combination with available means of tax funding, the use of tolls can be a useful method of constructing an improvement that might otherwise never be built or could take many more years to implement by using conventional tax funds alone.

Among the unique and interesting studies currently under way is one sponsored by Wisconsin's Department of Transportation to determine the financial feasibility of tolling the state's Interstate highway system. Preliminary findings indicate that the capital cost of implementing the toll-collection system could be recaptured in less than two years. Approximately 30 percent of the toll payments would be made by out-of-state motorists (15, p. 3; 16, p. 20; 17, p. 10). However, a critical deterrent to implementation of the toll concept in this instance is the preemption of sections of a long-standing, toll-free, tax-supported system of expressways.

In a companion document to the financial feasibility study report, Wisconsin Department of Transportation is expected to address the policy issues of adopting the toll concept.

In Pennsylvania, a study of several new toll roads, plus tolling of selected sections of the state's Interstate highway system, is being performed under the sponsorship of the Pennsylvania Department of Transportation.

The Illinois Department of Transportation, in concert with the Illinois State Toll Highway Authority, recently commissioned a feasibility study of two urban tollways in the Chicago area, facilities for which tax funds have been sought for many years with increasingly bleaker prospects for success. The study is unique in that innovative means of financing is the primary thrust of the investigations, including options such as transfer of the 90-10 Interstate highway system funds allocated to the proposed Crosstown Expressway and partial financing through the private sector by those business activities that would benefit through implementation (18).

In Houston, the Texas Turnpike Authority just released a preliminary financial feasibility study report indicating that the proposed Hardy Tollway, an urban radial facility extending from the vicinity of I-610 near downtown Houston north to the Montgomery County Line, would be feasible as a revenue-bond-financed facility at a bond interest rate of 9.875 percent but not at the current bond market rate of 11.25 percent. This could be a marginal project for revenue bonds guaranteed by other income sources (19).

From the state to a local governmental level, the regional planning agency in cooperation with the state department of highways and public transportation has commissioned a far-reaching study to examine new revenue sources for highways in Charleston, South Carolina (20). The study is designed to determine what reasonable sources of additional income might be developed to fund long-delayed improvements to the area's transportation system. One option to be examined includes tolling of one or more existing major bridges to produce a revenue pool from which to support rehabilitation of the existing structures and construction of one or more new bridges.

There is an increasing awareness of the need for a greater role by the private sector in financing and constructing transportation improvements. Whereas business interests may well derive direct benefits from a given improvement and be prepared to contribute to its implementation, the greater role may be an increased use of revenue bonds or direct private-sector construction and operation of a project; the challenge is to generate sufficient income to attract such private investment. Current tax programs in which investors can purchase, for example, an equipment system for the inherent tax advantages and lease the system to the operator are being carefully examined.

SUMMARY

The nation is in an "up" cycle in the popularity of toll facilities, from the point of view of both the public and public officials. Several conclusions, or objectives, stand out:

1. If federal legislation and policies can be changed, tolls will be placed on many existing road facilities as a means of raising additional local revenues. Current payback requirements make the tolling of most existing facilities unattractive to state and local governments. A more meaningful approach to meeting funding constraints would be the forgiveness of the original federal contribution with the understanding that the toll part of the system would no longer be permitted to receive federal funding allocations for maintenance or rehabilitation.

2. There is developing a major problem of dis-

continuing tolls on facilities when outstanding debts are liquidated. This can place a very heavy burden on state highway budgets when they have to assume maintenance and rehabilitation costs on roads or structures that have formerly been maintained from toll revenues. In this connection, it should be pointed out that many of the facilities to be converted from tolls to free roads have almost reached their design life, and rehabilitation costs can be enormous. To correct this situation and to recognize the proliferation and widespread acceptance of the toll concept, federal and state laws should be changed so that tolls can continue to be collected but with the specific understanding that the net revenues are to be used for highway purposes.

3. Combinations of private- and public-sector funding of major transportation improvements will undoubtedly continue to be more widely accepted. This might include tolling of selected portions of the Interstate highway system, probably mostly urban, where viable alternate toll-free routes exist. Precedent has indicated repayment of the original 90 percent federal funds contributed to construction. The challenge is to achieve a proper and workable blending of public- and private-sector funds to meet rapidly escalating needs of the nation's deteriorating transportation system.

4. The idea that toll facilities must always be self-liquidating could be put aside if public agencies are willing to pledge other highway revenues as a guarantee for debt services. This practice has been followed for some years in many states, and very sizable revenues have been added to the pool of highway funds.

Support for the tolling concept can be drawn from France, Spain, Italy, and Japan; in each country, the Interstate highway systems were designed and constructed as toll facilities, just as the U.S. system was initially conceived in the 1930s as a network of three east-west and three north-south toll roads extending from ocean to ocean and border to border.

There is no factual indication that the popularity of the automobile is diminishing, nor is it likely to diminish in the foreseeable future. It follows that the existing needs for highways can only become greater. Instead of talking about junking the automobile, it seems to make more sense to talk about ways of providing for it.

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