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Monitoring and Evaluation of State Highway Systems

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During the three immediately preceding decades, the U.S. highway system has been characterized by steady growth in total travel, increased system mileage and capacity, and net investment in both pavement strength and surface quality. The pattern for the coming decades is already becoming apparent, and it will be characterized by approximately stable overall traffic levels, maintenance and reconstruction of existing mileage, and probably some net disinvestment in the system as a whole. The data and the methods that highway planners have used to guide decisions during the previous phase of development of the highway system are unsuited to the problems of the coming decades, and state-level monitoring and evaluation functions will require a major reorientation in data collection and analytic tools.

Evaluation means estimating the incremental benefits and costs of alternative projects and programs, whereas monitoring means collecting the data that will support the evaluations. Instead of simply prioritizing projects within an exogenous budget constraint, highway planners must be able to distinguish those improvements that are worthwhile from those that are not, no matter how big or small the budget. Analysis capable of making this distinction attains a much higher level of technical and political credibility than analysis that is not so capable. Several states have taken steps in this direction (1,2) and the Federal Highway Administration (FHWA) supports an analytic package (3), but the pace of implementation needs to be accelerated.

EXISTING SYSTEM

The familiar distributions of highway mileage and vehicle miles of travel (VMT) by functional system are arrayed in Table 1. The vast bulk of the mileage is not included in the federal-aid system, and most of this excluded mileage is in rural county roads. A large share of these roads lack an all-weather surface. In contrast, travel is heavily concentrated in urban areas and on Interstates. Even at this level, then, the existence of a large extent of relatively low-volume roads is suggested.

A parallel set of numbers is constructed in Table 2 (4) as an attempt to portray the total value of the capital stock. Applying the average per-mile replacement cost estimates (including right-of-way) to the mileages in Table 1 yields total replacement costs for each functional system. This distribution of the value of the capital stock by functional class is much closer to the VMT distribution than is the mileage distribution; rural collectors and area service roads show a lower VMT per dollar of capital value. Figure 1 shows how the three distributions compare.

As a rough indicator of cost, the total replacement value can be converted to an annual figure by means of a capital recovery factor (CRF), i.e.,

Equivalent annual cost = CRF x total replacement value,

where the CRF includes both a lifetime and a discount rate. Using a CRF of 0.10 yields an annual capital cost of $174 billion annually, on the assumption that all highways are maintained and replaced as they wear out and both the land and other resources used could earn a market rate of return if put to other purposes. This is an estimate of the value of the resources that will be foregone by society in order to maintain the highway system as is in perpetuity. Nothing is implied about the benefits of doing so.

Actual expenditure on highways is a measure of cost that, under present financing arrangements, does not include any component for opportunity costs (e.g., the interest foregone on funds expended in highway construction). If the interest cost is removed from the replacement cost estimate above, the residual will represent expenditures for maintenance and reconstruction needed to offset the physical depreciation of the highway system. If we assume that 70 percent of the investment in a typical highway depreciates over a lifetime of 15 years, the total replacement value translates into an expenditure level of $81 billion that is required to be spent each year so as to keep the entire system in stable condition. Current expenditures for capital and maintenance by all levels of government are about $30 billion. These contrasts are illustrated in Figure 2.

Some of the information from the previous tables has been recombined in Table 3, which shows average daily traffic (ADT) and economic cost (including interest costs) per vehicle mile. Average volumes are substantial on some systems and meager on others, and the averages conceal an additional dimension of variation within the categories. Cost per vehicle mile (no administrative or externality costs are in-

Table 1. Total road and street mileage and VMT by functional system.

	Rural		Urban		Total		Rural		Urban		Total	
System	Miles	Percent	Miles	Percent	Miles	Percent	VMT	Percent	VMT	Percent	VMT	Percent
Interstate	31 334	0.8	9 114	0.2	40 448	1.0	133 597	8.7	159 452	10.4	293 049	19.2
Arterial	235 492	6.0	115 956	3.0	351 448	9.0	274 110	17.9	474 274	31.0	248 384	48.9
Collector	727 216	18.7	63 537	1.6	790 753	20.3	177 258	11.6	75 159	4.9	252 417	16.5
Local	2 284 756	58.7	427 727	11.0	2 712 483	69.6	85 114	5.6	150 169	9.8	235 283	15.4
Total	3 278 798	84.2	616 334	15.8	3 895 132		670 079	43.8	859 054	56.2	1 529 133	

Table 2. Average replacement cost per mile and total replacement cost by functional class.

	Replacement Cost/Mile (1978 $)					
	Rural		Urban		Total	
System	Amount	Percent	Amount	Percent	Amount	Percent
Interstate	77 614	4.5	109 131	6.3	186 745	10.7
Arterial	288 949	16.6	427 182	24.6	716 130	41.2
Collector	314 885	18.1	121 038	7.0	435 922	25.1
Local	228 476	13.1	171 091	9.8	399 566	23.0
Total	909 923	52.3	828 441	47.7	1 738 365	

Figure 1. Comparison of shares of mileage, VMT, and capital replacement value by functional system.

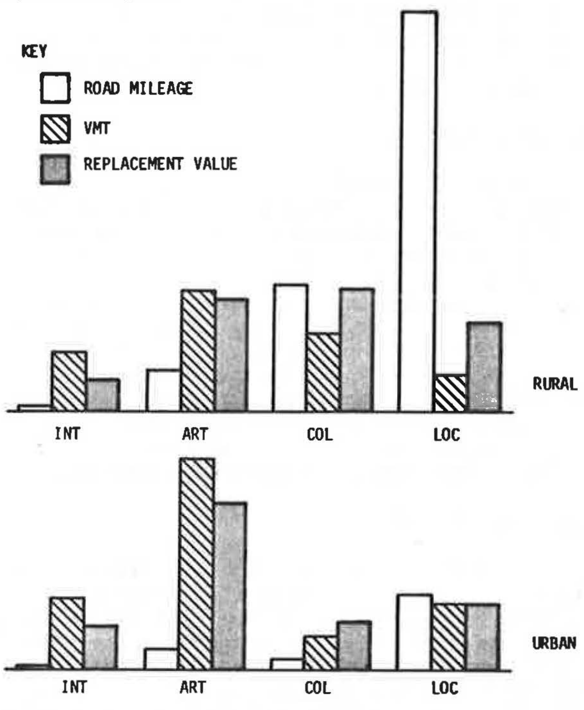


Figure 2. Comparison of current user charges, expenditures, and capital replacement for highways.

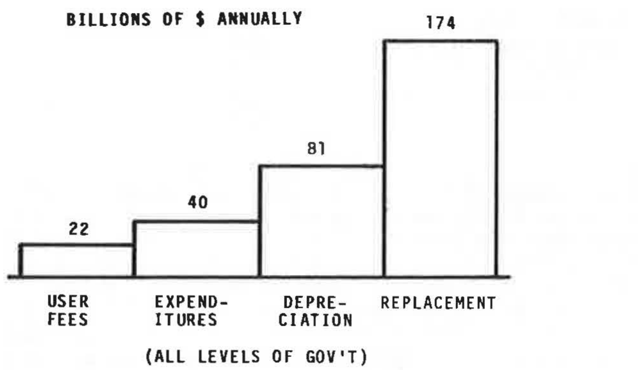
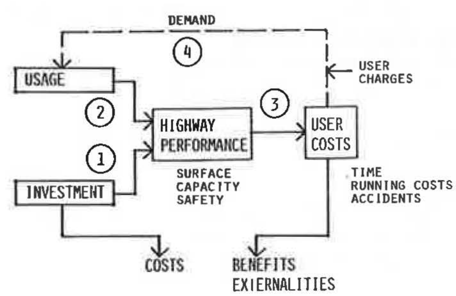


Table 3. ADT and average capital replacement cost per vehicle mile by functional system.

	Rural		Urban	
System	ADT	Dollars/VMT	ADT	Dollars/VMT
Interstate	11 681	0.06	47 932	0.07
Arterial	3 189	0.10	11 206	0.09
Collector	668	0.18	3 241	0.16
Local	102	0.27	962	0.11

Figure 3. Functional relationships between highway costs and benefits.



cluded) varies less than ADT but also suppresses some variation. Thus there are probably some urban Interstate segments the average depreciation costs of which exceed 27 cents/vehicle mile and some rural locals the costs of which are less than 6 cents/vehicle mile. No private operating or travel time costs are included in these figures; they are solely for the capital cost of the facilities.

With current user charges running about 1.5 cents/vehicle mile overall, users are not being asked to demonstrate a willingness to pay the long-run costs. The benefits to the users may exceed the costs incurred, but the evidence must come from sources other than, or in addition to, user charges. For the relatively low-volume rural roads, it seems unlikely that users would undertake nearly as much travel as they now do if user fees averaged 27 cents/vehicle mile. Although state and local taxpayers might be willing to carry some portion of the total cost, there is reason to doubt that they would tolerate general tax increases of the magnitude that would apparently be required.

Another dimension of the existing system is who uses it. The breakdown by VMT for 1977 (5), shown below, indicates that perhaps as much as 90 percent is passenger travel if pickups and vans are used primarily for that purpose. At the other end, about 5 percent of the travel is by heavy trucks. As a rough generalization, congestion is caused by passenger vehicles and pavement wear is caused by heavy trucks.

Vehicle Class	VMT (%)
Primarily passenger	
Motorcycle	0.8
Small automobile	15.4
Standard automobile	59.3
Pickup and van	17.6
Bus	0.4
	93.5
Freight vehicle	
Single-unit truck	1.9
Combination < 70 000 lb	2.7
Combination > 70 000 lb	1.9
	6.5

The VMT distribution by vehicle class is not the same across functional systems, so heavy vehicles are more likely to be concentrated on heavy-duty Interstates and primary roads. Under certain conditions, however, a very small amount of heavy-truck VMT on light roads can result in very heavy damage.

Thus the highway system overall is characterized by extremely skewed distributions. High VMT and high construction costs are concentrated in a small area of road mileage; heavy weight and high VMT are concentrated in a few vehicle classes. Small errors in measuring the parameters of these distributions at critical points may lead to large errors in investment programming and pricing, whereas large errors at other points may make very little difference.

CRITICAL INFORMATION NEEDS

Improved understanding of four types of relationships will be essential for sound management of the highway system in the coming decades. The four kinds of relationships, illustrated in Figure 3, are as follows:

1. Effects of improvements (surfacing, widening, strengthening, etc.) on highway performance characteristics (capacity, surface quality, safety);
2. Effects of use (freight and passenger vehicle travel) on highway characteristics;
3. Effects of highway performance characteristics on user costs (time, running costs, accidents); and
4. Effects of user costs and user charges on highway use.

In addition, information that will allow the impacts of improvements, user costs, and externalities to be stated in common units (such as dollars) is also needed.

Improvements and Highway Performance

On one side are expenditures for overlays, bridges, lanes, shoulders, medians, grading, tunneling, land acquisition, signing, signals, pavement markings, maintenance, repair, landscaping, and other construction and operating activities. On the other side are capacity, surface quality, strength, design speed, directness of route, safety, and other qualities associated with the service being provided. Relationships between the two sides include estimation of the expected life of pavements and geometric design.

Of the four kinds of relationships, effects of improvements on performance are the best understood. There is still much that is missing or could be improved, however, such as matching the incremental costs of different types of improvements in alternative combinations with the resulting performance changes.

Use and Highway Performance

The two primary variables here are congestion and pavement wear. Although both have been the subject of much attention, the basic empirical information is still weak. Consumption of capacity is measured in passenger car equivalents (PCEs), and the contribution of a given vehicle varies with the size and performance characteristics of the vehicle, the grade and other geometrics of the highway, and the mix of vehicles in the traffic stream. Each of these general sets of variables includes many specific measures, and the interrelationships between the sets are often important. For example, a vehicle that has a low power-to-weight ratio in mountainous terrain possesses a much different PCE on a two-lane road than on a four-lane road.

Pavement wear is thought to increase with the fourth power of the weight on the axle, a relationship that implies a high sensitivity at the heavy end. Aggregate evidence that Interstate highways are wearing out faster than expected suggests the importance of a better understanding of the usage-damage relationship. Weather and soil conditions are known to affect the vulnerability of pavement to axle-load applications, but the statistical experiments needed to verify and extend the relationships have not been undertaken.

Highway Performance and User Costs

Time has value to travelers as productive working time lost or foregone leisure and to goods movement as inventory costs. Pavement quality affects speed, wear, fuel consumption, and accidents. Geometric design and traffic volumes affect accidents as well as time and running costs. The relationships among these variables are, as with many of the other important relationships, highly nonlinear. Congestion reduces fatalities over at least some ranges, and poor pavement quality may have no effect on speeds for some geometrics. Many of these relationships are poorly understood, yet they are basic to the evaluation of investment in highway improvements.

User Costs and Demand

An essential relationship that has been almost completely overlooked is the demand for highway travel as a function of highway user fees and the performance characteristics of the highway system. Reduced pavement quality increases travel time and running costs, and this undoubtedly has a price effect on use, but the elasticities have been only roughly approximated.

Data Collection

Better information about these relationships will be acquired only by monitoring highway performance and travel over a substantial period of time, and these data-collection activities should be regarded as part of a continuous effort. Expenditures need to be tabulated by functional improvement and location so they can be linked to other data on segment-specific characteristics of use. Weigh-in-motion capabilities have improved to the point where no disruption of the traffic flow is necessary (for example, by using bridges). Measurement, recording, storage, and analysis of data can be heavily automated at unit costs that are steadily declining. Many kinds of data are available simply by tapping into an already existing data flow. These can be supplemented with case studies and specific highly focused sampling experiments and other low-cost studies. The most critical deficiency at present is the lack of an experimental design framework that will allow the data that are collected to be used for improving understanding of the key relationships.

ANALYSIS NEEDS

The data and empirical relationships described above are useful for many aspects of highway system management, but only three will be selected for further discussion.

Improvement Programming

Evaluation of the trade-offs among different types of improvements and different locations needs to be done in a way that allows the benefits of an improvement to be related to its costs. Current practice avoids this question by assuming that the budget to be spent is determined exogenously, and the only analytic problem is to prioritize improvements among the set of those available. The possibility that the budget might be sufficient to include some projects that are not worthwhile is not admitted, and the methods for prioritizing do not illuminate the trade-offs among types of improvements and locations.

A benefit-cost framework is clearly the suitable model for improvement programming, and using even the data that are currently available would produce better results than typical practice, with less effort. Without better information on performance characteristics and user costs, however, there is no method that will efficiently allocate resources to incremental highway improvements.

User Charges

The notion that users should pay something for the use of the highways has been accepted for a long time, but the concept that users should pay the economic costs of their use has not yet been established as clearly in the highway sector as it has in such areas as telephone service and utility rate structures. Deriving the maximum benefit from the highway system requires implementing user charges that more closely approximate the costs of use. If future investment in highways is to be concentrated in the most productive links and kinds of improvements, information on user benefits as derived from evidence of willingness to pay will be a necessary ingredient. Moreover, well-designed user charges will provide signals to users about how they can best economize (such as by spreading heavy loads onto more axles) on scarce highway resources. Financing the highway system calls for determining which vehicle classes to get the revenues from and which segments can only be supported if nonusers pay for them.

Design Standards

In the debate over the completion of the Interstate system, it has been recognized that design standards are not immutable and inviolable truths. In fact, many design standards are not cost-effective in many of the situations to which they ostensibly apply, and either the standards have been compromised in practice or overdesigned facilities have been constructed. While standards have many benefits, including the savings from not having to calculate the optimal design from scratch in each situation, they are only approximations to good solutions at best. At worst, they force expenditures for design characteristics that do not justify their costs.

Design standards can be evaluated from the benefit-cost perspective, drawing on the same body of information that improvement programming and user charge design do. With major expansion of the highway system no longer a likely future scenario, the costs of overdesign may be just as great as the costs of underdesign.

WHAT CURRENT PRACTICE CAN BE DELETED?

Most of the monitoring and evaluation activities that have been described above could be carried on with little or no additional cost if some of the less productive activities currently undertaken were reduced or dropped. State highway planning varies greatly from state to state, but several kinds of analysis are typical of many state agencies and are representative of the practice that could be improved.

Sufficiency Ratings

A messy and awkward analytic process, the construction of sufficiency ratings, is based on such weak and ad hoc information that the results contain very little of value. The same amount of analytic effort could be used with much of the same or substitutable data to produce more useful evaluations of the incremental benefits and costs of alternative improvement projects and programs.

Long-Range Plans

Major multiyear long-term capital planning never reached a very high level of development in most states, and the need for such planning has fairly obviously declined. The method lingers on, however, because many planners believe that not having a plan is professionally irresponsible. Streamlined versions are available for those who still need to make plans, and other programming techniques can be used by those less constrained.

Cost-Allocation Studies

There is often a political need for some document that will justify raising fuel taxes by a few cents, and budget-allocation studies have generally served this purpose. Highway user-charge design is, as already stated, a very important function for state highway planners, but elaborate cost-allocation studies are not the technically sound route to this end. If budget-allocation studies are inescapable, they can still be done with an eye toward minimizing their costs.

Indirect-Impact Studies

Studies of land use around interchanges and the multiplier effects of highway construction employment on local communities have little relevance to highway investment decisions, and they are generally unnecessary for other purposes as well.

CONCLUSIONS

The success with which states finance their highway programs in the next decade will depend on two analytic capabilities: the design and implementation of efficient user-charge instruments and the selection of links and subsystems in which to invest.

User-charge design requires knowledge of the economic costs created by each vehicle class on each type of road under relevant conditions; investment programming requires knowledge of how improvement costs translate into benefits. For these kinds of tasks, information is needed on four kinds of relationships: improvements and highway performance, use and performance, performance and user costs, and user costs and use. Both the structural knowledge of these relationships and their empirical calibration have been insufficiently developed to support current analysis needs, and the bulk of the job of creating this information base is likely to fall to the states.

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