

# APPLICATIONS OF BENEFIT-COST ANALYSIS: THE SELECTION OF "NONCONSTRUCTION" PROJECTS

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The traditional benefit-cost framework, frequently used to evaluate construction projects, is used to analyze "nonconstruction" activities of highway agencies for the purpose of improving resource allocation within and between programs. Drawing from three examples of maintenance projects and from the parks and the bicycle trails programs, the authors demonstrate that difficult-to-value variables such as safety, recreational experiences, and benefits to bicycle riders can be evaluated with benefit-cost analysis. In the hypothetical cases of safety benefits from shoulder paving, multiple benefits from pothole patching, construction of parks for campers and day users, and bicycle route construction for commuters, the values of benefits required to justify the investments are calculated. The optimum frequency for maintenance projects is also examined. The conclusions are that techniques exist to improve project selection within many programs and that a better understanding of the versatility of benefit-cost analysis will lead to its more frequent use.

• A CONTRACT was entered into by the Oregon State Highway Division and Oregon State University (OSU) for OSU to provide the analytical framework, economic analysis, and, in some cases, data to improve resource allocation in the highway division. Essentially, the study was designed to indicate what contribution economics could make to decision-making on a variety of organizational levels. The research resulted in a six-section report (1) that treated topics as general as intermodal resource allocation and as specific as the selection of highway projects.

This paper draws partially on sections of the report that deal with the role of economics in evaluating highway division programs and with allocating resources to specific "nonconstruction" activities. A generalized benefit-cost framework is applied to problems that are frequently not evaluated by such analysis. If employed successfully, the suggestions offered in the paper will facilitate comparisons among projects in particular programs (e.g., within the maintenance section) and between projects in different programs (e.g., between the construction and maintenance sections).

After a discussion of the role of economics in evaluating public investments, the general benefit-cost framework is outlined. Within this context, the application of economic analysis to activities in the maintenance, parks, and bicycle route programs is examined.

## THE ROLE OF ECONOMICS

Central to most definitions of economics is the concept of allocating scarce resources to alternative ends. That is, economics is generally perceived as a discipline concerned with deciding how to use a limited amount of time, money, labor, machinery, or other scarce resources to best achieve an objective or set of objectives. This concept can be applied within wide limits. Broadly defined, economics is a science of decision-making. It is concerned with benefits and costs (or advantages and disadvantages) of alternatives and is relevant to all of man's activities. In this context, to say

that one is applying economics to decision-making really means that he is considering all relevant factors, both positive and negative, before making a decision.

Very narrowly (and inappropriately) construed, the term economics is used to signify the undertaking of an activity with the lowest monetary outlay. For example, when there are several alternate highway investments and the least expensive one is chosen, the choice is sometimes mistakenly referred to as one "determined by economics."

Economics, however, is not limited to a consideration of costs or quantifiables; the discipline is equally concerned with benefits and with nonmonetary, unquantified variables. Viewed in this way, economics provides a framework within which the inputs of all other relevant disciplines can be combined and expressed so as to assist the decision-maker in an otherwise very difficult task.

### ECONOMIC ANALYSIS IN HIGHWAY AGENCIES

The need to organize and evaluate effects (i.e., benefits and costs) of highway projects is widely recognized, especially with the recent emphasis on developing Action Plans and preparing environmental impact statements. This recognition could be expected to lead to an intensified application of economic analysis and, more specifically, of benefit-cost techniques, but this does not seem to have taken place. Casual observation suggests that economics has not been used so frequently as possible for several reasons:

1. Economic analysis, as mentioned above, is seen as a means of determining the "least cost" approach to constructing a project. This decision, which really does not require an economist at all, can be made after the more important questions of project feasibility or desirability have been answered. When the discipline is interpreted so narrowly, it is understandable that it is not viewed as very helpful in evaluating the numerous project effects that are possible.

2. Highway agencies often lack the interest or expertise to correctly apply economic analysis and benefit-cost techniques. Other project selection tools such as sufficiency and deficiency indexes have been more popular (2, 3).

3. Traditional benefit-cost analysis (frequently treated as the equivalent of economic analysis) compares only some road user benefits with highway agency costs. It is too restrictive to include most project impacts. It is usually not understood, however, that many observed economic effects can be traced to road user benefits. In most cases, road user benefits represent a large share of the actual net gain from a highway project (4).

4. Some analysts have responded to the apparently narrow benefit-cost framework by trying to include other effects such as indirect economic benefits; a frequent by-product of this approach is double-counting. The result is an expanded benefit-cost ratio that is difficult to interpret, is often "stacked" to make a project look worthwhile, and lacks credibility.

5. The interest in displaying all project effects in large matrices is growing. This represents a potentially productive approach, but there are still many problems with rating and weighting effects to arrive at a decision concerning project selection. The intuitive appeal of showing all effects, though, has led to a reduced interest in the narrower benefit-cost framework.

The result of these factors is less frequent use of economics, even though its organizational contribution could be valuable, and of benefit-cost analysis, although it is still one of the best evaluation techniques for considering many kinds of projects. There is no doubt that benefit-cost methodology can improve project selection and that it is a great deal more flexible than is usually thought to be the case—notwithstanding problems with multiple objectives and project effects that are difficult to evaluate.

It appears that the organizational constraints of the past and the narrow categorical funding arrangements for highway programs are changing. The movement to departments of transportation and broader federal funding requires increased use of project selection techniques that facilitate comparison between types of programs and alternate transportation modes.

## BENEFIT-COST ANALYSIS

Before we consider several adaptations of benefit-cost methodology to highway agency programs, it is useful to describe the general analytical framework. Ideally, according to the benefit-cost criterion, projects would be undertaken as long as the present value of project benefits was at least as great as the present value of project costs. That is, a project passes the benefit-cost test if

$$\frac{B_1}{(1+r)} + \frac{B_2}{(1+r)^2} + \dots + \frac{B_n}{(1+r)^n} \geq \frac{C_1}{(1+r)} + \frac{C_2}{(1+r)^2} + \dots + \frac{C_n}{(1+r)^n}$$

where  $B_i$  is the benefit enjoyed by society in the  $i$ th year,  $C_i$  is the cost borne in the  $i$ th year,  $n$  is the last year in which the project generates either benefits or costs, and  $r$  is the rate at which society discounts time. In most real-world agencies, the budget is fixed; therefore, projects should be selected so that the sum of the difference between the discounted benefits and discounted costs over all projects is maximized.

Passing the benefit-cost test is not sufficient to make a project worthwhile when all benefits and costs cannot be quantified; nonquantified effects can and often do outweigh the measurable impacts that are treated in the standard benefit-cost calculations. Even in these cases, however, benefit-cost analysis facilitates the organization and evaluation of other benefits and costs.

The possibilities of applying the benefit-cost framework to a variety of investments are elaborated below. The examples represent cases in which there is uncertainty about the benefits, because of either the value of the benefit per beneficiary, the number of beneficiaries, or a combination of these factors. It is demonstrated that unlike projects can be compared to a greater extent than is usually recognized.

## MAINTENANCE PROJECTS

Although benefit-cost analysis is frequently applied to construction investments, it is seldom used to evaluate maintenance projects, even though the objectives and functions of the programs are very similar. Examples are given of how typical maintenance projects might be evaluated with standard benefit-cost techniques.

### Case 1: Treatment of Safety Benefits From a Shoulder Paving Project

Benefit-cost analysis is rarely used in cases where the important project effects are difficult to evaluate in dollar terms. Shoulder paving is such a case in that its primary purpose is a rather elusive benefit: highway safety.

Our behavior, individually and as a society, confirms that we place some positive, but finite, value on added safety. The problem of including safety effects in the conventional benefit-cost analysis is that one must place a specific value on a unit of safety, (e.g., on accidents prevented or on a life saved). Resistance to the selection of a particular value causes many analysts to reject a benefit-cost framework. Unfortunately, however, this does not eliminate the need to consider safety effects in project selection; it simply means that the implicit value for safety will vary widely from project to project.

The alternative suggested here is that the benefit-cost analysis be "reversed" so that the solution becomes the value that would have to be placed on safety benefits to justify selection of the project. In the example, safety benefits are expressed in terms of an annual dollar figure. Existing accident data allow the answer to be further refined.

The advantage to this approach is that the decision-maker need not select a precise value for safety benefits; rather, he must decide only whether the likely safety benefits are worth more than the cost of the project, a variable that can be estimated with some degree of precision.

Consider the following hypothetical project to replace gravel shoulders with pavement along a 10-mile section of highway. Assume that (a) the highway has annual traffic of 1,000,000 vehicles or 10,000,000 annual vehicle-miles, (b) the initial cost of



the paving project is \$100,000, (c) the additional annual maintenance cost for the highway strictly due to shoulder pavement is \$5,000, (d) the project life is 20 years, and (e) the discount rate is 8 percent. The problem can be stated as

$$\$100,000 = \frac{X - \$5,000}{(1 + 0.08)} + \frac{X - \$5,000}{(1 + 0.08)^2} + \dots + \frac{X - \$5,000}{(1 + 0.08)^{20}}$$

where X is the minimum dollar value of increased safety per year that the paved shoulders must provide to justify the maintenance project. Solving for X yields \$15,185.

An examination of accident data allows more detailed statements about the safety benefits that would be needed to justify undertaking the projects. Given a cost per accident of \$2,186 (based on accident data on the Oregon state rural system), there must be 6.95 fewer accidents per year along this section of highway to yield a benefit-cost ratio of one. Given an average accident rate of 2.55 per million vehicle-miles, 25.50 accidents would have been expected along the 10-mile section of highway each year. To reduce this number by 6.95 accidents constitutes a reduction of 27.3 percent.

Other general maintenance functions can be evaluated in the same manner. The essential feature of the proposed procedure is that it requires explicit consideration of the major benefit, increased safety, even though it is difficult to measure. Of the other eight general maintenance functions of the Oregon State Highway Division, four seem to be undertaken primarily for a single benefit that has been troublesome to measure. As with shoulder paving, installation of guardrails and maintenance of traffic control facilities are primarily intended to increase safety on the highway system. Among the other functions, care of roadside vegetation and roadside cleanup are undertaken mainly for the comfort and convenience of the road user. As in the shoulder paving case, the benefits required to justify projects carried out for these functions can be expressed in various ways that may ease the decision-making problem. For example, the required value per passing vehicle for roadside cleanup could be calculated. These calculations of required benefits allow the decision-maker to postpone the valuation problem until it is expressed in a manner that may be more meaningful for him and then to compare unlike projects more rationally.

### Case 2: Treatment of Multiple Benefits From a Pothole Patching Project

The difficulty in estimating the effects of many maintenance projects does not lie mainly in valuation; these effects tend to be the standard benefits corresponding to fast, safe, and efficient travel. The methodology of valuing them is reasonably well formulated, but rather in measuring the amount of effects. This second case illustrates how the investigator can use the benefit-cost framework to calculate a set of benefit packages that would justify undertaking the maintenance project. Even if he cannot measure the effects, the analyst can restate the selection problem in a way that facilitates project selection.

Consider the following example (Fig. 1). Assume that (a) a pothole patching project on 10 miles of highway with a lifetime of 1 year will cost \$10,000 and (b) the roadway involved has annual traffic of 1,000,000 vehicles. (In this example, the benefits to road users are not discounted for the length of time between cost and benefit because the period involved is so short.)

User benefits include time saved, reduced vehicle operating costs, and increased safety. Time saved is assumed to be worth \$3.00 per hour per vehicle, and each accident prevented is estimated to be worth \$2,186.

Figure 1 shows benefits that are required for a benefit-cost ratio of unity. If no accidents are prevented by the project, time and vehicle operating savings must be worth project costs of \$10,000 to justify the investment. This amounts to \$0.001 per vehicle-mile or 1.2 seconds per vehicle-mile. Thus, a savings of 1.2 seconds per vehicle-mile or \$0.001 in vehicle operating cost per vehicle-mile or any linear combination of the two will yield total benefits from the project equal to the total cost of \$10,000. If benefits are estimated to be at any point above the line labeled 0 accidents prevented, the estimated benefit-cost ratio exceeds unity; the opposite holds for any

Figure 1. Multiple benefits from a patching project.

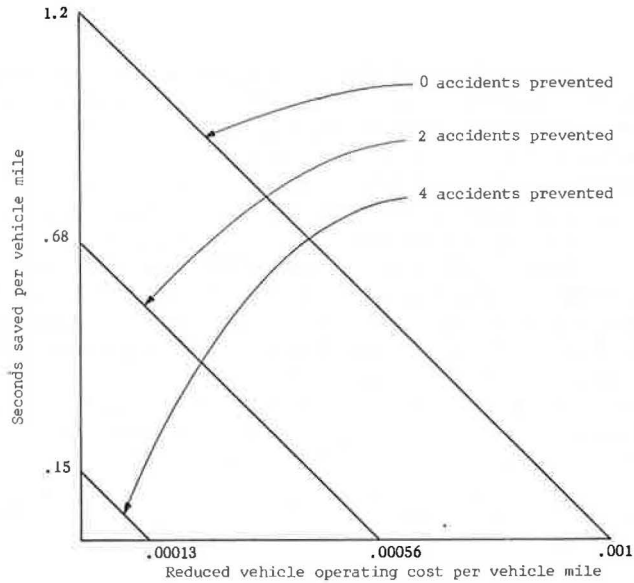


Figure 2. Required values for overnight campers and picnickers to justify park development.

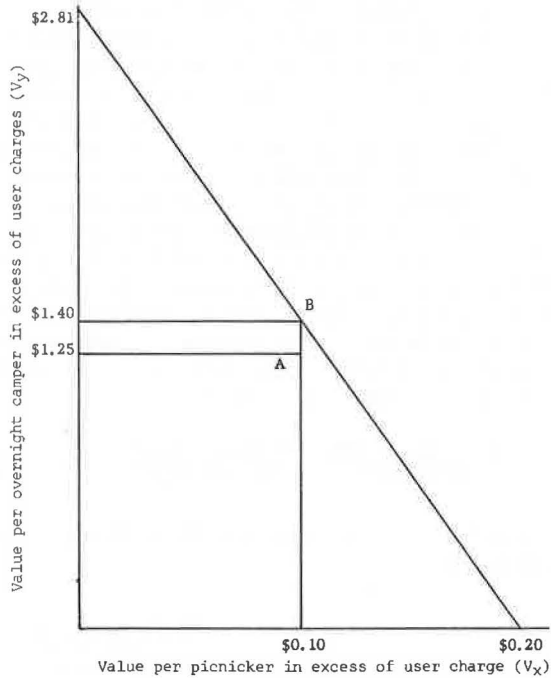


Table 1. Benefits of bicycle routes and expenditures justified per mile.

Path Length (miles)	Average Trip Length (miles)	Commuters	Present Value of Benefit (dollars)	Expenditure per Mile (dollars)
4	2	100	21,300	5,325
		500	106,500	26,600
		1,000	212,500	53,100
5	3	100	9,000	1,800
		500	44,900	9,000
		1,000	89,000	17,800
7	5	100	37,300	None justified
		500	186,700	
		1,000	374,700	

pair of values below that line. If accidents prevented are estimated to be greater than zero, the necessary time and operating cost savings for a benefit-cost ratio of one would be reduced. This is reflected in Figure 1 by required benefit lines down and to the left of the 0 accidents prevented line. For example, if two accidents would be prevented by the pothole patching project, the combination of time and savings benefits for a benefit-cost ratio of unity is described by the line labeled 2 accidents prevented.

As in case 1, the decision-maker must consider whether the actual benefits are likely to be as large as the required benefits depicted in Figure 1. The proposed technique does not select projects; it merely recasts the properties necessary for wise decisions in ways that are more intelligible. It assists the decision-maker; it does not replace him. Still, its role is sufficiently illuminating that it may help to ensure that the best projects will be selected and the worst will be omitted.

Many of the maintenance functions are similar to pothole patching in that they yield benefits of more than one type that are difficult to measure. Project selection and evaluation for any of the functions that can be so characterized may be facilitated by the procedure suggested for pothole patching. Functions that definitely involve the full range of standard road user benefits are repair of roadway surfaces, snow removal, and sanding.

### Case 3: Selection of Optimum Frequencies for Maintenance Projects

For most of its functions, a maintenance section probably has a set of strategies that can be adopted to achieve the highway benefits for which the program is intended. In general, the feasible strategies can be ordered from very frequent but inexpensive tasks to much less frequent but major maintenance projects. For example, the maintenance section may be able to choose between patching a highway each year or carrying out a major overlay every 10 to 12 years. Benefit-cost analysis can be useful in selecting the optimum frequencies for different maintenance tasks.

In this case, it is assumed that road user benefits of a constant amount per year, \$1,000, can be obtained through either of two maintenance strategies. In one strategy, the highway agency must spend \$100 per year for each of the 20 years that the highway is expected to yield services for a total of \$2,000. In the second strategy, the agency spends \$4,000 for maintenance at the end of the tenth year of operation; nothing is expended in the other years. As in case 1, an 8 percent discount rate is used to convert costs and benefits to present value terms. (Problems related to the comparability of benefits in the twentieth year for the two cases are ignored.)

The problem can be stated as follows:

$$PV_1 = \frac{\$1,000 - \$100}{(1 + 0.08)} + \frac{\$1,000 - \$100}{(1 + 0.08)^2} + \dots + \frac{\$1,000 - \$100}{(1 + 0.08)^{20}} = \$8,836$$

The present value of the net benefits of the highway, if it is maintained once at the end of the tenth year, is

$$PV_{10} = \sum_{t=1}^{20} \frac{\$1,000 - M_t}{(1 + 0.08)^t}$$

$$PV_{10} = \$7,965$$

and

$$\begin{aligned} M_t &= \$4,000 \text{ for } t = 10 \\ M_t &= 0 \text{ for } t \neq 10 \end{aligned}$$

The calculations for this example show that the policy of undertaking some maintenance annually is superior to the policy of undertaking a major maintenance project in

the tenth year. The present value of the net benefits of the highway with annual maintenance is \$8,836, and the present value of the net benefits for the 10-year maintenance policy is \$7,965. Thus, following the annual expenditure method gives net benefits of \$871 over the less frequent maintenance approach.

This particular example is not intended to suggest that more frequent maintenance is always better than less frequent maintenance. This, too, can be overdone. For this example, it might be concluded that a maintenance pattern of every 2 or 3 years would yield a present value in excess of the present value that was obtained for annual maintenance expenditures. In fact, it is appropriate to consider several reasonable maintenance patterns to be sure that the optimum frequency for any type of maintenance project has been determined.

The type of investigation suggested here could be used for all general maintenance functions. Still, it may be more important to determine the best frequencies for some maintenance functions than for others; this would seem to be particularly the case if a failure to maintain at one frequency means that the highway agency will need to undertake an entirely different maintenance activity. This characterizes the maintenance functions that "protect the investment." Maintenance of highway drainage facilities, inspection and repair of structures, and repair of roadway surfaces are all functions designed to protect the investment. For each, better maintenance frequencies may be discovered or confirmed by investigating alternatives, as this third case suggests.

### PARKS AND RECREATION

In Oregon, the state parks and recreation program is included under the jurisdiction of the highway division. Benefit-cost analysis has not been used in making decisions in this program even though there is a definite similarity between selecting and developing land for recreational purposes and choosing highway construction projects. In fact, the use of benefit-cost analysis for the parks program may be less controversial than its use for highways because the impact of park construction and use on nonusers is usually relatively small. For the most part, the benefits derived from a park accrue to users, and the costs are reflected in highway division expenditures on land acquisition, development, and maintenance of the park.

The primary problem in using benefit-cost analysis in the park program is in estimating the dollar value of the recreational experiences enjoyed by park users. The proposed analytical strategy to cope with this problem is to solve for the user benefits that would be necessary to justify the project rather than the ratio of benefits to costs. Given the relatively accurate estimates of the number of prospective park users and the nature of their use, the corresponding required value per use can be determined.

Consider the following example. The following assumptions are made:

1. Land acquisition cost is \$1,000 per acre,
2. Campsite development cost is \$4,000 per site,
3. Picnic site development cost is \$1,000 per site,
4. Annual use per picnic site is 3,300 people,
5. Annual use per campsite is 350 people,
6. Annual user charges equal annual maintenance and operation cost,
7. Park life is 25 years,
8. Discount rate is 8 percent, and
9. A 100-acre park site accommodates 20 campsites and 30 picnic sites.

The land for this park would cost \$100,000 (100 acres  $\times$  \$1,000 per acre), and the development cost would be \$110,000 (20 campsites  $\times$  \$4,000 per campsite + 30 picnic sites  $\times$  \$1,000 per picnic site); total acquisition and development cost is \$210,000.

The only other cost associated with the proposed park would be for operation and maintenance. Assumption 6 above is that these costs are just equal to park user fees. Thus, the appropriate benefit-cost test in this case compares park benefits in excess of park user charges with acquisition and development costs of \$210,000.

Given the assumptions above, 175,000 campers will stay overnight and 2,475,000 people will use the picnic facilities in the proposed park over the next 25 years. Other



things being equal, though, the value of a camping experience or a picnic in the park is worth less the longer society must wait for them. The appropriate adjustment is to discount recreational experiences for this waiting time. At an 8 percent discount rate, the present time equivalent of the 175,000 nights that campers would spend in the park over the next 25 years is 74,723. Similarly, the present time equivalent of the 2,475,000 picnickers who would use the proposed park is 1,056,802.

The benefit-cost test determines whether these use levels are worth \$210,000 plus the park user fees. The solid line in Figure 2 shows the possible combinations of values in excess of fees for picnic and camping uses that would be required for a benefit-cost ratio of unity, given the levels of use mentioned above. Any pair of values above the solid line would give predicted user benefits in excess of costs and, therefore, a benefit-cost ratio in excess of unity. Conversely, any pair of values below the line yields a benefit-cost ratio of less than one. For example, suppose that the value per picnicker in excess of any user charge is known or judged to be more than \$0.20. In this case, the proposed park would pass the benefit-cost test even if the value per overnight camper is zero. In contrast, the benefit-cost ratio would be less than unity if the values per camper and picnicker are \$1.25 and \$0.10 respectively (A in Fig. 2). A \$0.10 value per picnicker would require a \$1.40 value per camper to justify the park through equating the values of benefits and costs (B in Fig. 2).

### BICYCLE ROUTES

In 1971, Oregon was placed in the forefront of bicycle route legislation when a law was passed that called for no less than 1 percent of the funds received by the highway commission (from federal or state sources) to be expended for footpaths or bicycle routes. According to this law, each highway construction, reconstruction, and relocation project must include bicycle routes or footpaths unless

1. They are contrary to public safety,
2. The cost of the trails is disproportionate to their use, or
3. The sparsity of population or other factors indicate no need.

These qualifications effectively leave the highway division without guidelines on where bicycle routes should be placed and what quality of routes should be constructed. Economic analysis provides some direction.

For simplicity, in the example it is assumed that all bicycle route users are commuters (5). The analysis of bicycle commuters is similar to the standard benefit-cost approach for highway construction. Conventional assumptions concerning the value of time and vehicle operating costs are used, and commuter trips of several lengths are treated. It is assumed that bicycle riders would have to be diverted from automobiles to the new bicycle route; then the difference between a person's costs as an automobile driver and a bicycle rider is compared.

Because there is only minimal knowledge on how many riders might be expected, the approach is to calculate the changes in time costs and operating costs for an assumed number of commuters for several bicycle route lengths. It can then be determined how many bicycle riders are required to justify the construction of bicycle routes of various lengths.

Table 1 gives the present value of the benefits to commuters, assuming a 20-year life for bicycle routes and an 8 percent discount rate. The other assumptions are as follows:

1. The bicycle route has a 20-year life,
2. Automobile operating cost is 11 cents per mile,
3. Bicycle operating cost is 2 cents per mile for commuters on the 2- and 3-mile trips and 1.5 cents per mile on the 5-mile trip,
4. The value of time is 3.9 cents per minute (\$3.00 per hour per car),
5. Automobiles travel 20 mph for the 2- and 3-mile trips and 25 mph for the 5-mile trip,
6. Bicycles travel at 10 mph,
7. The automobile driver requires 5 minutes more to park and walk than does the bicyclist,



8. Average automobile occupancy is 1.3 people,
9. Users of bicycle paths of 4, 5, and 7 miles have average one-way trip lengths of 2, 3, and 5 miles, and
10. There are 120 workdays on which it is possible to ride a bicycle.

The expenditure per mile indicates the expenditure justified per mile to just balance the 20-year benefits, i.e., that would yield a benefit-cost ratio of one.

Generally, the analysis indicates that as many as 750 bicyclists would need to use a bicycle route to justify an expenditure of approximately \$40,000 per mile (the average cost of a path) and that only a shorter route would be feasible. As the length of a bicycle route increases, more bicyclists would be required. It seems unlikely, based on these calculations, that a route of more than 5 miles would be economically justified. Ridership on constructed bicycle routes has averaged approximately 30 a day, hardly enough to justify construction of routes.

The analysis, of course, does not pretend to represent all of the benefits (or costs) from bicycle riding. Dealing with what is known or can be reasonably assumed, however, shows how much the nonquantifiables must be worth if the bicycle path is to be justified. For a 5-mile bike route with 100 commuters per day, for example, an expenditure of only \$9,000 is justified. With an average construction cost of \$40,000 per mile, it would require \$200,000 to build the bicycle route. Consequently, the additional benefits to society must be valued at approximately \$190,000 if the bike route is to be constructed.

### CONCLUSIONS

The major conclusion emerging from the foregoing analysis is that it is not necessary to throw up one's hands so soon. Techniques and data exist to improve decisions that are now based primarily on judgment and intuition. To the extent that such investments as maintenance projects, parks, and bicycle routes can be quantified, there is a more rational basis on which to compare all agency activities when allocating funds.

Progress should be made in quantifying more project effects and in displaying and evaluating all consequences of highway agency investments. It is important to recognize, however, that it is not necessary to wait for these developments before improving project selection techniques; the framework already exists to enhance decision-making. Only an effort to use it is required.

### ACKNOWLEDGMENT

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