SCHEDULING OF HIGHWAY IMPROVEMENTS

Edward Miller, Office of Systems Analysis and Information,
U.S. Department of Transportation

Although a showing that benefits exceed costs indicates that a project should be constructed sometime, it does not necessarily indicate that the optimum time for construction is now. Likewise, the highest priority projects are not necessarily those with the highest benefit-cost ratios or the highest internal rates of return. Instead, for most highway projects the optimum time of construction is when annual benefits minus maintenance costs first exceed the product of the discount rate and the capital cost of the project. If funds are not available to build all desired projects now, the projects to be built first should be selected in order of their priority ratio. In the simplest case the priority ratio is the first-year benefits minus maintenance and operating costs, divided by the capital cost of the project. Given the usual situation of steadily increasing benefits, highway improvement projects are relatively risk-free investments.

•THE GOAL of highway planning and scheduling is to select a program of projects for which the present value of benefits minus costs is at a maximum, subject to any relevant annual budget constraints. The constrained budget problem discussed here differs from the usual formulation in which there is a fixed total amount to be spent at once. [For a discussion of the traditional problem of obtaining maximum total benefits from a total fixed amount to be spent at once see Hirshleifer, DeHaven, and Milliman (1).] This is considered a more realistic formulation because, for capital investment programs of any magnitude, it is not possible to meet all needs within a single year. Even if the legislature would appropriate the required funds, limitations on resource availability and planning capabilities would make it impossible to expend all of the funds in a short period of time. Certainly, it is unrealistic to plan for simultaneous construction of all needed highways. In the discussion here, highway projects will be considered to be independent of each other, although it is realized that this assumption is also often unrealistic. It will also be assumed that all projects have already been examined for economic feasibility and found to have benefits that exceed costs on a present value basis. [For a discussion of how to calculate benefits see publications by AASHO (2) and Winfrey (3).]

PROJECT TIMING IN THE ABSENCE OF A BUDGET CONSTRAINT

It is sometimes asserted that a project should be built now if its discounted benefits exceed its discounted costs. This is incorrect; such a test only shows that a project should be built sometime.[1]

This can be shown by a simple example. Consider a new town that is scheduled to be built 5 years from now. Building the road leading to it will cost $1,000,000 and produce benefits of $1,000,000 per year once it is open. Suppose we are using a 10 percent discount rate. The present value of benefits is $6,100,000 for a benefit-cost ratio of 6.1. Such a road is clearly worth building and would probably have a high priority in

[1] Similar conclusions to those drawn here have been reached by Margolin (4, 5); also see Arrow (6). For a highly mathematical discussion of the problem of transportation project scheduling that comes to some of the same conclusions expressed here see Beenhakker (7).

Sponsored by Committee on Transportation Programming, Planning and Evaluation.

any list of projects ranked by benefit-cost ratios. Yet it would clearly be a mistake to build the project now, giving it priority over roads that are already needed. If built now, the road would sit idle for 5 years before being used. Obviously the correct time to build the road is just before the new town is constructed when the road is needed.

In this extreme case, the error in relying solely on the benefit-cost ratio is clear. A more realistic case is obtained if, instead of an entirely new town, we use one that is expected to grow very rapidly. A traditional benefit-cost ratio calculation may give a high ratio because of the large volume of traffic that the road will carry in the future. Yet it would be a mistake to give the road high priority now, because the amount of traffic that would use the road initially would be small and unable to justify immediate construction of the road. [An example of an otherwise good study that fails to take this into account is Hejal's economic priority model (8).] The remainder of this paper will discuss the problem of when to build a project that is justified and how to assign a priority to such projects.

The optimum time for building a project is the time when, with all costs and benefits discounted to the present, the excess of benefits over costs is at a maximum. Only in special circumstances will the discounted value for net benefits (benefits minus costs) pass through a maximum at the exact point where benefits are equal to costs. In all other cases construction of a justified project as soon as discounted net benefits are positive will lead to premature construction of the project.

Let us start the discussion by considering a case in which the cost of building a road between two growing cities does not vary with when the road is built. However, the traffic on the road will grow over time with growth of the cities. For simplicity assume that the highway does not influence the location of population and that the traffic carried by the highway varies only with the calendar year, not the year in which the highway was constructed. The proposed design for the highway will have a high enough capacity so that it will be able to handle many years of future growth in traffic without serious congestion. Thus benefits will grow continuously at the same rate as traffic. This is a simplified model of the situation applicable to most rural roads and many rural Interstates.

Let us consider how one would choose the optimum time to construct such a road. The goal is to select the time of construction for which the present value of net benefits passes through a maximum. It is a straightforward procedure to calculate the present value of benefits for different years of construction and then to select the one with the highest value. However, there is an intuitive approach that gives some insights into the problem.

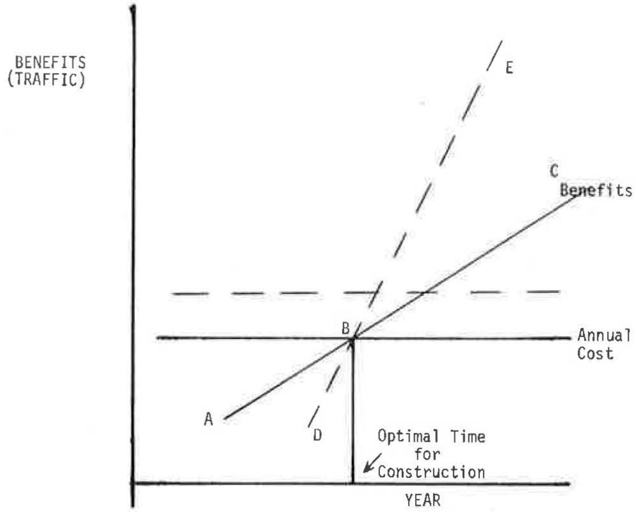
The fact that benefits are increasing while costs remain constant shows that the economic justification for the project is constantly improving. Thus, if the project is justified for construction in any one year, it will be even more worthwhile in future years.

The decision reduces to whether the project should be constructed now or should be postponed till a future year. (Remember that all projects being considered have already been found to have benefits that exceed their costs.) It is not necessary to decide now at exactly what future year the project will be worth constructing.

The saving from postponing construction for one year is the interest on the construction cost of the road plus the maintenance expense for one year. The benefits lost by postponing construction for one year are those for the first year. To decide whether road construction should be postponed, all that is necessary is to compare the first year benefits with the savings in costs. (If benefits are growing, it will often happen that the discounted present value of benefits exceeds one, but the project should not be built yet. Since traffic and benefits increase over time for virtually all roads, a policy of building a road as soon as it has a benefit-cost ratio in excess of one leads to premature construction.)

The foregoing situation is shown in Figure 1. The horizontal line is the annual cost of the project interest, amortization, and maintenance. By assumption it does not vary with when the project is constructed. The line AC represents the benefits as a function of time. (They probably rise at least as rapidly as traffic.) The optimal time for project completion is B, when the annual benefits are equal to the annual costs.

Figure 1.



It should be noted that projections of future traffic are required only for design purposes and to be sure that at time B the present value of benefits exceeds the present value of costs. Because of the rising traffic levels on most highways, there will be little doubt about project justification by time B. (The time for which the benefit-cost ratio was exactly one will occur before time B.) Thus information on future traffic is less important than it is under the traditional benefit-cost criteria. The need for projections of future traffic for design puposes still remains, of course.

Notice that there is an interaction of growth of traffic and the optimum time of construction through the design and cost of the road. If a road has a high rate of traffic growth, the design traffic load will probably raise the cost of construction and postpone the optimum time of construction. In Figure 1 the dotted horizontal line represents the cost of a road built to higher standards to handle a higher level of traffic. It can be seen that the optimum time of construction is later for the road on the fast-growing route than for the road along the slow-growing route. What is happening is that a higher level of traffic is needed to justify the more expensive road than is needed for the less expensive road.

DEVELOPMENT PERIODS

The case discussed in the foregoing was one in which the benefits and amount of traffic varied only with calendar time, not with the date of construction of the highway. This is probably an accurate description of the situation for many highway improvement projects, especially the smaller ones that do not cause enough of an improvement in travel time to generate much traffic or produce changes in the location of industry. However, there are new roads for which the traffic in any given year depends on when the road was built. For instance, a new road may lead to the construction of new factories along it. Traffic to and from these factories would use the road, thus raising the benefits. Hence, the 1980 benefits from a road might be greater if it had been constructed in 1970 than if it had been built in 1975. This is because factories locating in the area between 1970 and 1975 would have located so as to make maximum use of the road.

This situation is easily handled. The present value of benefits from constructing the road now are computed. Likewise the present value (as of now) of benefits is computed for construction one year from now. The difference in the two present-value figures represents the loss of benefits from postponing construction by one year. It includes not only the loss of the first year's benefits but also the discounted value of the decrease in benefits in each future year from benefits not having had a chance to build up.

EFFECTS ON TIMING OF DIFFERENT TYPES OF ROADS

It was shown that the traditional benefit-cost criteria of building as soon as benefits exceeded costs leads to premature construction of roads where benefits would normally increase over time. The more rapid the growth of traffic, the more premature construction is likely to be. In general, roads serving the slowly growing farm and mine populations will have the lowest rate of growth of traffic. The error of premature construction is least likely to have been committed for these roads. In contrast, a road connecting two rapidly growing cities or connecting a city with a resort area may have a very rapid growth of traffic. Such a road if built at the time when its benefit-cost ratio first becomes one will be very premature. Essentially, the benefit-cost ratio indicates that there is a future need for the road such that the benefits over the life of the road will exceed the costs. However, the benefit-cost ratio itself says nothing about when this need exists. In the case of the road connecting two rapidly growing cities, one may build a road that is definitely needed far in the future too soon if decisions are based on the benefit-cost ratio.

THE NOW-OR-NEVER CHOICE

A benefit-cost ratio provides an indication of whether a road should be built now or never. However, it is seldom that one is faced with a now-or-never decision on a new road. Postponement of construction is usually a realistic option. Where one often gets the now-or-never option is in the design of a road and the selection of specific improvements to be included. For instance, the decision to eliminate a curve or to construct an overpass for a road that is already under construction may be of the now-or-never type. If these are not built during the initial construction it may be impractical to come back and do it later. For planning decisions of this type, the correct rule is to build the project if the present value of added benefits exceeds the present value of added costs. This is so even though the annual costs may prove to be more than annual benefits for the early years of the life of the project.

CHANGES IN CONSTRUCTION COSTS OVER TIME

The discussion so far has assumed that construction costs do not change over time. In practice they do for many reasons, such as residential construction on the right-of-way. Costs of delay include not only the loss of benefits but also any escalation in costs that are expected. For instance, if the cost of constructing a road is estimated to be $1,000,000 today but will be $1,100,000 next year because of construction of a subdivision on the right-of-way, a year's delay will increase costs by $100,000. If costs were expected to decrease (perhaps due to technological progress), the cost of delay would be negative. Likewise, if delay is expected to change the present value of maintenance costs (such as by increasing the length of the road), the change in the present value of all future maintenance represents the cost of delay.

In considering changes in the cost of construction with time, changes due solely to inflation should be excluded unless such changes are also included in the estimates of benefits. It is customary to estimate both benefits and costs assuming a constant price level. Probably the most important cause of increased construction prices is construction of buildings along the right-of-way that must be demolished for the highway. Increased prices for land purchases might also be considered as increased cost for the highway. However, from an economic viewpoint the real cost of using land for a highway is the opportunity foregone to use the land for another purpose. Land values represent the capitalized value of the returns from such foregone uses. Hence, increases in land values usually represent real increases in the annual costs of using land for highways, not just a one-shot increase in costs. However, if highway planners wish to include the savings in the right-of-way costs for land purchases in their programming, the way to do it is to include the avoidance of price increases as one of the benefits of early construction.

A real benefit of early construction will often be the reduction of relocation expenses and severance damages. Although not included in the financial costs of highways, the social savings from construction of a highway before development of surrounding land should be included as a benefit of early construction. There are a number of such social benefits. One is avoiding the disruption that occurs from putting a highway through an established community. Indeed, if development has not yet occurred, expressways may even serve to provide desirable boundaries between neighborhoods. Patterns of friendship, church and school attendance, and locations of stores will adapt to the highway rather than being disrupted by it. Although most of these costs are nonfinancial, it should be noted that more overpasses are likely to be required to permit continuation of established patterns of community life if the highway is built after community development rather than before. Likewise, with early road construction (or at least announcement of the route), tributary road systems may be laid out so as to connect efficiently with the new highway, saving the cost of reconstructing these routes later and reducing costs for future road users. Likewise, large employers, shopping centers, apartments, and places of amusement can be located so as to utilize efficiently the new highway. This is likely to minimize the total cost of construction for feeder roads and will also reduce travel times because of the smaller distances being driven on slow local roads.

Finally, environmental problems are likely to be reduced if the highway is built before the surrounding land is fully developed. Developers, knowing that houses adjacent to the expressway will be hard to sell, may refrain from building right next to it as long as suitable land is available. Thus a thin buffer zone of undeveloped land may develop along a new expressway. If adjacent land is developed, it is more likely to become commercial, industrial, or apartments than single-family residential. Such uses are less affected by the proximity of a highway, partially because of a smaller area of windows. If development does occur adjacent to an already existing highway, the design is likely to be such as to minimize adverse effects, using techniques such as suitable location on the lot, placing the short end of a building perpendicular to the highway, placing rooms with a small window area (such as garages) adjacent to the highway, minimizing areas of windows on the noisy side of the building (especially if a view of the highway is not considered aesthetic), and installation of storm windows and central air-conditioning. Such design techniques can greatly reduce the adverse effect of a highway on a residential structure but are difficult to apply if the building was put up before the highway.

Finally, people differ greatly in the extent to which they are annoyed by highway sounds and views. If development occurs after highway construction, those who are extremely sensitive to such factors can avoid buying property adjacent to the highway. If the highway is constructed through an established neighborhood, those exposed to the disadvantages will be a representative selection of the population, including some who will be very much bothered by the highway. Some people are likely to move who would not have had to move if they had been able to take the highway into account when they chose their original location.

Thus there are a number of nonmarket benefits from early construction of a road that should be included in the analysis of the optimum time of construction. When added to the cost savings, early construction of roads in developing areas (or at least advance purchase of right-of-way) will often be found to deserve high priority. These factors are not included in traditional benefit-cost ratios or internal rates of return.

MULTI-STAGE PROJECTS

Reference was made to advance acquisition of right-of-way as one technique for avoiding development on the right-of-way. This is just one example of staged construction. It is possible to determine whether stage construction is economical or not by trying different combinations of timings for the construction of different stages and selecting the one for which the present value of benefits minus costs is greatest. If this shows staged construction to be desirable, the optimal timing for the first stage can be determined by the methods described earlier. For instance, for advance acquisition of right-of-way, the major loss from postponing the expenditure is the increase in the economic cost of the land.

Once the first stage of the project has been executed, the second stage is included as an additional project and the analysis repeated. Because the first project has already been completed its cost is excluded from the costs of the second stage. For instance, where the second stage is to actually build the road on an already acquired right-of-way, the benefits from construction are primarily the first-year benefits to the users (and perhaps greater benefits in future years), and the costs are the annual costs of maintenance for one year and the interest on the construction costs (but not right-of-way acquisition costs) for one year. The cost savings from earlier acquisition of right-of-way are not included.

THE RISK OF PREMATURE CONSTRUCTION

Benefit-cost ratios are very sensitive to the level of benefits in future years. A project may become uneconomic if benefits do not grow as rapidly as projected. This is often used as an argument either for using a cutoff benefit-cost ratio higher than one or for building a risk factor into the interest rate. However, the risk of constructing a road that should not have been built is less using the timing criteria than using the benefit-cost criteria.

Risks can be divided into two categories. One comes from misestimating the rate of growth of traffic and benefits. The other comes from errors in estimating the level of first-year traffic and the resulting level of benefits. The first type of error is likely to be most important for improvements to an existing road where the current traffic provides a good guide to the traffic after completion of the project. However, where a new road is being constructed, errors in the forecast of initial-year traffic are likely.

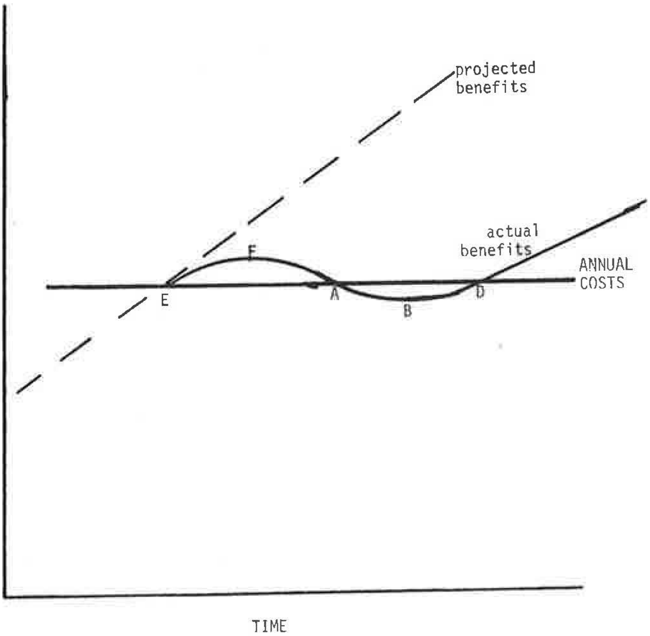
For an improvement to an existing road that is not expected to change the level of traffic, the chance of making a serious mistake in timing is small. To show this, let us return to the case of a project with benefits that do not vary with how long it has been since a project was constructed and construction costs that do not vary with time (to permit graphing). Figure 2 indicates how first-year benefits vary with costs.

For the road construction to have been an error, it is necessary that the benefits in future years drop below the annual cost and that the discounted value of the area under the annual cost line bounded by ABD exceed the value for the area over it bounded by EFA.

Errors in the estimation of the rate of growth of traffic do not cause errors in project timing as long as traffic and benefits increase over time. Because population and per capita travel usually increase, there is relatively little risk of error, and certainly much less than is inherent in the traditional test of whether the benefit-cost ratio exceeds unity. Because construction often must be begun a year or two before the desired date of completion, it is necessary to make a short-run forecast of traffic growth. There is a small risk that this short-run forecast will be in error. Of course, if the design of the road varies with the estimated traffic, errors in prediction will still have the effect of reducing expected net benefits below net benefits with the expected traffic. Even here the widespread use of rules of thumb and prescribed standards for highway design means that the highway design is often little influenced by moderate errors in prediction. In essence, for the typical highway improvement project the element of risk is much less than would be expected from the sensitivity of the benefit-cost ratio to errors in the growth rate for traffic.

The other type of error arises from mistakes in forecasting the initial year's traffic. This is most likely for entirely new roads. With growing traffic, the effect of an error in forecasting the initial year's traffic is merely that the project is built prematurely. The loss from premature construction is that the benefits for the first few years are less than the annual costs of the road. For instance, consider a road with benefits growing at 5 percent per year. Suppose that the only cost was $1,000,000 for construction with an interest rate of 5 percent. Thus the savings from postponement of construction are $50,000 per year. The initial estimates of first-year benefits had been $50,000

Figure 2.



per year. Instead they were only $40,000 because the amount of diversion from other routes had been overestimated. However, the 5 percent straight-line growth rate (based on population growth) is correct. The calculation of the loss from what turned out to be premature construction is as follows:

Year	Benefits	Present Value Factor	Present Value
1	40,000	1.00	40
2	42,500	1.05	40.476
3	45,000	1.1025	40.816
4	47,500	1.150625	41.081
5	50,000	1.21551	
			162.373

The present value of benefits gained for the 4 years of premature operation (at 5 percent) is $162,400. The construction cost of $1,000,000 was incurred 4 years early. The present value of the delayed construction is $ 822,700. Thus, early construction raised the present value of construction costs by $177,300. Because this increase in construction costs exceeds the value of the benefits by $14,900, the road construction was premature. However, it should be noted that a 20 percent error in the estimate of initial-year benefits produced a loss of only 1.5 percent of the project cost as a result of premature construction. This is in spite of the fact that the error reduced the benefit-cost ratio by 20 percent. The actual cost of forecasting errors is much less than is suggested by the sensitivity of the benefit-cost ratio to errors in the initial-year estimates.

It should be noticed that the loss from a wrong forecast would be 20 percent of the construction cost if growth of benefits did not eventually justify the road. This illustrates how growth of traffic serves to reduce the risk in many highway investments. In general, the higher the growth rate of benefits, the lower the risk.

THE LIMITED BUDGET CASE

The discussion so far has assumed that there are funds enough to build every road at the optimal time for construction. However, it often happens that the funds are not adequate to construct all the roads that should be built by the standards described here. It then becomes necessary to select the most desirable roads for each year's construction. This is what economists call the constrained-budget problem. [The various dynamic programming methods for handling this problem will not be discussed here. It should be noted that computational difficulties limit such methods to situations where there are only a small number of alternatives.]

The procedure for handling this case is to calculate the loss of net benefits from postponing a project by one year. This will be (the present value of benefits for construction now minus present value of benefits for construction one year earlier) plus (the present value of costs for construction one year from now minus present value of costs for construction now). This gives the benefit for construction now instead of a year later. If the ideal time of construction is now, this increase in the present value of new benefits will be positive. If not all such projects can be built, the goal then is to postpone those projects for which the loss from postponement is lowest. This can be done by dividing the benefits from early construction by the construction cost to give a priority ratio. If projects are ranked using this ratio and then selected until the construction budget for that year is exhausted, the least-postponable projects will be selected.

The selected projects are then removed from the list of alternatives and the process is repeated for a period one year later. In general, all projects will appear better because of increased traffic. By repeating this process for successive years, the optimum construction budget can be derived for future years.

LIMITATIONS OF THE METHOD

The foregoing method of solution applies only to the case where priority ratios decline over time. This indicates that some progress is being made toward reducing the backlog. This is the situation with the current highway program. However, if an extremely sharp decrease in highway funding was expected, this condition might not be met. Then one might want to build a project now that would not be needed until some time in the future because the funds would not be available to build it in the future. When this happens, the relevant choice is no longer between construction now and construction one year in the future, which was the assumption on which this discussion was built.

DISCLAIMER

The views presented here are the author's and do not necessarily reflect the views of the U.S. Department of Transportation.

REFERENCES

1. Hirshleifer, J., DeHaven, J. C., and Milliman, J. W. Water Supply, Economics, Technology, and Policy. Univ. of Chicago Press, 1960, pp. 169-174.
2. Road User Benefit Analysis for Highway Improvements. American Association of State Highway Officials, 1960.
3. Winfrey, Robley. Economic Analysis for Highways. International Textbook Co., Scranton, Pa., 1969.
4. Margolin, S. A. Public Investment Criteria. M.I.T. Press, Cambridge, 1968, pp. 74-79.
5. Margolin, S. A. Approaches to Dynamic Investment Planning. North Holland Publishing Co., Amsterdam, 1963.
6. Arrow, K. Optimal Capital Policy, the Cost of Capital, and Myopic Decision Rules. Annals Inst. of Statistical Mathematics, Vol. 16, No. 1-2, 1964, pp. 21-30.
7. Beenhakker, H. L. The Optimal Year for Starting a Transportation Project. Revista Brasileira de Transportes, jul./set. 1966, Suplemento No. 1.
8. Hejal, S. S. An Economic Priority Model for Rural Highway Improvements. Purdue University Joint Highway Research Project, Rept. 28, 1970.