On the Optimum Level of Effort for Evaluating Low-Volume Rural Road Projects in Developing Countries

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ABSTRACT

Reviews of several rural road projects in developing countries financed by the United States Agency for International Development have revealed that the level of effort in the evaluation of rural road projects has varied widely. The cost of evaluating projects can be significant, but if the higher cost results in better selection of projects, the possible increase in net value of the road program may make a more intensive evaluation worthwhile. A model based on probability theory and parameters believed appropriate for current low-volume road projects, where the benefits flow mostly from increased agricultural activity, are used to show that project benefits would increase if more effort were devoted to evaluation. Cursory evaluations such as "windshield surveys," though perhaps valuable as a screening tool and inexpensive, do not appear to have the accuracy required to maximize the net value of the road program. It appears that for the road projects considered, the so-called rapid rural appraisal techniques, costing about $400/km, are close to the optimum, striking a proper balance between cost of evaluation and benefits achieved. It is only roads with a high cost of construction for which the more elaborate evaluation methods involving in-depth surveys are required. It was found that compared with the benefits foregone by not enough analysis, the cost of the evaluation is small; thus it is better to err on the side of too much analysis than not enough.

The recent series of ex-post impact evaluations (4) by the U.S. Agency for International Development (AID) have shown that the level of effort applied to the economic justification of their road projects has varied widely. The evaluation of the Jamaica Feeder Roads project, an example of a high level of effort, involved massive data gathering in the zone of influence of each road and detailed analyses of these data on computers. At the other extreme, the Liberia Rural Access Roads project involved only a simple reconnaissance lasting a few weeks and followed by a brief analysis by a transportation expert. The difference in cost between these two approaches was, of course, large. The question is whether the return from a higher level of investment in economic evaluation procedures is worth the cost and what the best level of effort might be.

The purpose of this paper is to present a model that assists in establishing the optimum level of effort for the economic justification of a low-volume (say, less than 20 vehicles per day) road project. In this model, the cost of the evaluation effort is balanced against the benefits to be gained from the increased reliability of the evaluation. This reliability is defined as the probability that economically feasible road projects are accepted and infeasible ones are rejected.

The model is then applied to yield useful guidance on the level of effort that should be expended on selection of low-volume feeder road projects. For example, it turns out that, for the average AID feeder road project in which benefits are primarily determined by the additional value of agricultural production and other economic activity induced by the road project, the optimum level of the evaluation effort should be that of a rapid rural appraisal (see section on Estimation of the Parameters for definition) costing about $400 to $600/km of road. Furthermore, the model demonstrates that once the optimum level of effort has been reached, increases in the level of effort will result in only a slight reduction in the net value (benefits minus construction cost minus evaluation cost) of the road program. However, decreasing the level of effort from the optimum will result in a sharp dropoff of the net value of the road program. Thus, it is better to err on the high side of investing in evaluation; that is, it is better to spend too much on evaluation than not enough.

THE MODEL

The model developed in this section relates the net value of the road construction program with the level of effort devoted to the selection of the roads. Typically, about 30 candidate road projects would be proposed for the rural roads construction program, of which perhaps 20 are economically feasible. The net value of this program is calculated by adding the net present value (NPV) of the benefits of each road that is constructed (and because of imperfect evaluation techniques, some infeasible road projects will probably be included in the construction program) and subtracting the cost of the evaluation of all the projects. The NPV of the benefits for a road project is the value of the incremental agricultural production plus the savings in vehicle operating costs plus the savings in maintenance cost plus other benefits (such as those from increased ease and more convenient passenger travel) minus the construction cost of the project. The NPV can be calculated by using standard economic analysis techniques such as those described by Carnemark et al. (2).

The NPV of the benefit for economically feasible road projects is, of course, higher than that for

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infeasible ones. An opportunity is lost, therefore, if, because of unreliable evaluation procedures, an economically infeasible road project is selected or a feasible one is rejected. However, selection involves economic analysis and data collection efforts that are not cheap, and there is a possibility that the gains from more reliable evaluation are nullified by the high costs of the evaluation. It is this trade-off that is analyzed in the model described here.

It should be pointed out briefly that the term "economic evaluation" refers to more than the calculation of costs and benefits and subsequent production of a list showing which road projects are economically feasible. In this paper the term refers to the broader role that economic evaluation plays in increasing benefits and reducing costs. For example, through effective interaction with the rest of the design team, economic evaluation assists in increasing the benefits by identifying constraints (other than access) that diminish the beneficial impact of a road project and by proposing effective measures to eliminate these constraints. At the same time, economic evaluation can reduce costs and increase benefits by determining the proper mix between labor and capital during construction, exploring alternative alignments, or establishing the proper mix between road design standards and maintenance effort.

GENERAL DERIVATION

A brief description of the model is presented. It is assumed that the project has a fixed construction budget and that the roads to be constructed are selected from a long list of candidates. To keep the model simple, it will be assumed that all roads are of equal length and have equal construction cost. Dropping this assumption presents no analytical problem but would unnecessarily complicate the model.

The road projects are evaluated one by one until the road program budget is exhausted; this will happen when the budget equals the cost of construction plus the evaluation of the roads. The list usually contains both "good" and "bad" projects. (To save space, the term "good" will be used for an economically feasible project and "bad" for an economically infeasible one.) Some candidate road lists will be of high quality, containing a large number of good projects. High quality may result, for example, if projects are screened before being included on the list. Or, because local governments are often much aware of the transport needs of their communities, lists composed at the local level are sometimes of high quality.

Depending on the reliability of the evaluation procedures, a good project will have a certain probability of being correctly identified as good. Similarly, a bad project will also have a certain probability of being mistakenly identified as good. The reliability of the selection procedure will of course depend on the level of effort devoted to it and on the inherent difficulty of evaluating the projects. Road projects that are, for example, located in a remote area of a country that has been little studied and where few data are available will be more difficult to evaluate than those located in areas that have been well studied.

Using probability theory, equations are derived that determine the number of good and bad projects that are constructed and, as a function of the quality of the candidate road list, the reliability of the evaluation procedures and the number of road projects that are evaluated. Then, with the budget constraint and the cost of constructing and evaluating a project, an equation is derived that gives the total number of projects that are evaluated.

$$NC = (W - W1) + R1 \tag{1}$$

$$W = N * (1 - PG) \tag{2}$$

$$W1 = B1 * W = B1 * N * (1 - PG) \tag{3}$$

$$W - W1 = N * [(1 - B1) * (1 - PG) + G1 * PG] \tag{4}$$

$$R1 = G1 * R = G1 * N * PG \tag{5}$$

where

NC = total number of projects constructed,
W = number of bad projects evaluated,
W1 = number of bad projects evaluated as bad,
R = number of good projects evaluated,
R1 = number of good projects evaluated as good,
N = total number of projects evaluated,
PG = probability that a candidate project is good,
B1 = probability that a bad project will be evaluated as bad, and
G1 = probability that a good project will be evaluated as good.

Thus, NC can be expressed as follows:

$$NC = N * [(1 - B1) * (1 - PG) + G1 * PG] \tag{6}$$

By introducing the budget constraint and the cost of constructing and evaluating the projects, the equation for the total number of projects evaluated (N) can be derived. The cost of constructing the good projects plus the cost of constructing the bad ones plus the cost of evaluating the projects (B) is

$$B = N * [G1 * PG * CC + (1 - B1) * (1 - PG) * CC + EC] \tag{7}$$

where

B = budget available for the road program ($),
CC = construction cost of a project ($), and
EC = cost of evaluating a project ($).

Solving for N,

$$N = B/\{[(1 - B1) * (1 - PG) + G1 * PG] * CC + EC\} \tag{8}$$

The number of projects eliminated by the economic evaluation (NE) is

$$NE = N * [PG * (1 - G1) + B1 * (1 - PG)] \tag{9}$$

The number of economically feasible projects constructed (NG) is

$$NG = N * PG * G1 \tag{10}$$

And the number of economically infeasible projects constructed (NB) is

$$NB = N * (1 - PG) * (1 - B1) \tag{11}$$

It can be seen that the total number of projects evaluated as given in Equation 8 is the sum of the good projects constructed (Equation 10) and the bad projects constructed (Equation 11). The total value of the road program is the sum of the benefits added by each project minus the construction cost of the good and bad projects and the evaluation costs of all the projects.

The value of the benefits added by a good project (VG) and that of the benefits of a bad one (VB) can be expressed as the product of the project's benefit/cost ratio and the construction cost. This follows simply from the definition of the benefit/cost ratio. For example, if the construction cost for a project is $700,000 and the benefit/cost ratio is 1.2, the benefits of the project can be calculated as 1.2 x $700,000 = $840,000. For an economically infeasible project with a benefit/cost ratio of 0.8, the benefits would be 0.8 x $700,000 = $560,000. Assuming that the good projects have an average benefit/cost ratio of GS and the bad ones have a ratio of BS, the net value of the road program (VAL) is

$$VAL = (GS * CC * NG) + (BS * CC * NB) - (NC * CC) - (N * EC) \qquad (12)$$

The first and second terms of the foregoing equation represent the sum of the benefits of the good and bad projects. The third term gives the total construction cost of the projects, and the fourth term gives the cost of evaluating the projects, including those that were not constructed because they did not pass the evaluation.

Calculation of the net value of the road program requires estimation of a complex set of parameters, which will be discussed in the next section.

ESTIMATION OF THE PARAMETERS

To exercise the model and to enable the drawing of some broad conclusions regarding the optimum level of effort for evaluating rural road projects certain parameters must be estimated: the probability that a project is good (PG), the probabilities that a good project is identified as good (G1) and that a bad project is identified as Bad (B1), and the average economic return (benefit) of an economically feasible and an economically infeasible project.

It must be mentioned, however, that ex-post evaluations of feeder road projects are rare, and information on the results of the evaluations is even more scarce. The author knows of only a few evaluations that generated data useful to the estimation of these parameters. These sparse data do not instill much faith in the precision of these estimates. For this reason, care was taken to draw only those conclusions from the model that are not sensitive to the precision of the parameter estimates. The model, of course, was useful in examining this sensitivity.

Probability That a Project Is Good

The probability that a project is good (PG) depends on the amount of background work that went into the preparation of the list of road candidates. Usually this list is prepared by the host government, and its preparation may or may not involve some screening of the projects. A few historic projects will be examined to get an indication of what the range of PG might be.

In a recent road project in Haiti, for example, the candidate road list simply contained projects that were deemed desirable; no attempt had been made to apply quantitative criteria to screen the projects from the point of view of economic feasibility. For this project, ex-post evaluation revealed that about 450 of the 600 km of candidate road projects were economically feasible, and the ratio of 450/600 = 0.75 may be taken as an indication of the probability that a candidate road project is economically feasible. It is not an exact indicator because the ex-post evaluation techniques used to establish the feasibility were not perfect; nevertheless, this procedure provides a useful indicator of PG for the Haiti project.

Another example is a rural road project in the Dominican Republic. The candidate road projects had been screened with cursory data on traffic levels and agricultural potential. Ex-post evaluation indicated that an average of 81 percent of the candidate road projects were found to be economically feasible.

For an Asian Development rural road project in the Philippines, the candidate road project list was compiled from recommendations submitted by local government officials. Though the screening was not quantitative, it was based on judgment by persons familiar with the transport needs in their regions. Ex-post evaluation procedures established that 84 percent of the road projects were indeed economically feasible.

These three examples and other cases not cited here indicate that, depending on the degree of screening, the range for the parameter PG would be 0.75 to 0.85. It would be possible to have lower values of PG for cases in which the roads are in an area with especially low potential (such as areas in the Sahel in Africa) and where screening is applied infrequently or not at all. But it would be surprising if PG fell below 0.6. For the upper limit of PG a value of 0.9 could be considered reasonable. Thus, the range for PG is estimated to fall between 0.6 and 0.9.

Evaluation Efficiency

The values of B1 and G1 are a function of the level of effort devoted to the evaluation. These levels of effort can range from no evaluation, which is comparable to selecting projects by flipping a coin--heads, the project is good, tails, the project is bad--to comprehensive in-depth surveys to collect the necessary data on agricultural and other activities in the zone of influence of the project.

Statistical theory suggests that the reliability of the evaluation process will increase as the level of effort devoted to the evaluation increases but that this relationship is governed by the law of diminishing returns. Thus, at low levels of effort it will be easy to achieve large gains in reliability, but at the higher levels an increase in effort may produce only a small increase in reliability. The relationship is also a monotonically increasing one in that an increase in the level of effort will never result in a decrease in reliability. Finally, the reliability should asymptotically approach the value of perfection (100 percent accuracy) as the level of effort increases beyond bound.

There are a number of mathematical functions that have been found useful in science and industry to depict such a reliability function. The one selected for this paper is a simple one (the data do not warrant more sophistication) and is defined as follows:

$$R = A - 0.5 * [1 - \exp(-M * K)] \qquad (13)$$

where

R = reliability or probability of correctly classifying a project, expressed as either B1 or G1;
K = level of effort devoted to the evaluation ($/km of road);
A = initial reliability at a zero level of effort; and
M = parameter specifying the efficiency of the evaluation procedures.

In theory, the level of effort may assume any value between zero and infinity. In this paper, however, the discussion will be limited to the four levels of effort that have traditionally been applied to road projects. Ex-post evaluation of a number of past road projects is used to establish the relationship between reliability and the level of effort and to estimate the parameters A and M.

The lowest level of evaluation effort, as mentioned earlier, is simply none. In this case, projects may be selected at random, by flipping a coin, for example. This selection process is repeated until the road construction budget is exhausted. At this practically zero level of effort the reliability of correctly classifying a project as good or bad will be 50 percent, and the intercept A of the reliability curve is therefore 0.50.

Given that the value of A is 0.5, it can be shown that M, the efficiency parameter, can be expressed in terms of the level of effort (K) and the reliability (Y) as

$$M = \log \{[(1 - Y)/0.5]/-K\} \qquad (14)$$

In this equation, it is stated that if the level of effort K that went into the evaluation and the reliability Y that was achieved are known, the efficiency can be calculated. In estimating the reliability curve for G1, for example, if the level of effort expended on the evaluation was $1,000/km of road and the ex-post evaluation showed that a reliability of 0.86 was achieved, the value of M for the G1 curve would be 0.00127. If for that same level of effort of $1,000/km it was possible to achieve a reliability of 0.96, the value of M would increase to 0.0023. For the reliability of the B1 curve, the parameter M can in principle be estimated the same way. If for the level of effort of $1,000/km a reliability of 0.86 could be achieved for B1, the value of M would also be 0.00127. Carrying out the value of M to five decimal places is not an attempt to achieve spurious precision; rather, it is necessary because of the great sensitivity of R to M.

M has to be carefully distinguished from the other parameter, K, also found in the curve for evaluation reliability and that relates to the level of effort devoted to the evaluation. K is measured in dollars per kilometer, or the cost to evaluate 1 km of road, and is proportional to the size of the evaluation team and their time spent. As will be described later, this cost is about $40/km for the windshield survey. M is a variable that gives the increase in reliability that can be expected from an increase in level of effort K. The higher the value of M, the more rapidly reliability will increase with level of effort.

For example, if M = 0.001 and the level of effort is increased from $400/km to $425/km, the reliability will increase from 0.665 to 0.673, an increase of 1.2 percent. But for M = 0.002 and for the same increase in K, the reliability will increase from 0.775 to 0.786, an increase of 1.4 percent.

M can be considered proportional to the skill of the evaluation team and the amount of readily available information on the road and its zone of influence. The value of M will be high for an evaluation in which the evaluation team is well trained and experienced in rural road evaluations and has available a number of studies and surveys pertaining to the road. Conversely, for an evaluation in which the team is unskilled and there are few reliable data on the road and the surrounding region, the value of M will be low. Typically, as indicated in the section on the estimation of the parameters, the average efficiency of evaluation teams used for estimating the value of M is around 0.002, though there may have been instances in which the efficiency dropped to 0.001.

The lowest value for M is zero. This value implies that the evaluation team is totally incompetent and that its classification of projects is no better than that achieved by flipping a coin. In theory, there is no upper limit to the value of M. In practice, however, it does not appear that M could exceed the value of 0.04; this value implies that, even for the lowest meaningful level of effort, the windshield survey, the team could correctly classify about 90 percent of the roads. Though this efficiency is high, it could conceivably be reached by well-trained evaluation teams that have the benefit of earlier studies of the road and its zone of influence.

It was not possible to determine a reasonable range for the reliability of classifying a bad project as bad. Projects classified as bad were, of course, not constructed, and for the projects investigated in this study, the data on the bad ones had been discarded. It would be reasonable to assume, however, that the efficiency for the process of classifying good projects as good would be similar to that for classifying bad projects as bad. In this paper, therefore, it will be assumed that M is the same for both processes.

To review briefly, at this point the value of A is known, and the intercept of the reliability curve for B1 and G1 is 0.5. It has been assumed that the value for the efficiency (M) is the same for both reliability curves. It remains to estimate the value of M. To do this, some historic projects will be reviewed, and the level of effort (K) that went into the evaluation will be calculated and the reliability (R) that was achieved will be estimated.

The nature and the cost of the various levels of effort, such as the windshield survey, rapid rural assessment, and the in-depth survey, that have been applied to past rural road project evaluations will be discussed first. This will be followed by the estimation of the reliability. By combining the reliability and level of effort it will be possible to estimate the value for the efficiency (M).

Windshield Survey

In the windshield survey, the information for evaluating rural roads is collected by a quick visit to the candidate projects by a team of engineers and economists to obtain an impression of the actual or potential level of economic activity along the road and of the costs of road construction. No attempt is made to quantify the extent of cultivated areas for various crops, the density of population, or the location of sources of borrow for construction. Such a survey is cheap and rapid and, if done by a competent team, a distinct improvement over no evaluation. This approach was applied to the Liberia Rural Access Roads II project.

The time required to survey a project consisting of, say, 500 km of feeder roads would take the two-person team about 2 weeks. Allowing 1 week for office work and 1 week for contingencies, the approximate cost of the windshield survey would be about $20,000. This assumes that the work is done by expatriates and includes the per diem cost of a jeep plus driver and the cost of airfare from the United States to a less developed country in Africa. The average cost of the windshield survey would be about $40/km of surveyed road.

Few ex-post evaluations have been carried out for projects that used a windshield survey, but their reliability is estimated to be somewhat less than 60 percent. This estimate is supported by an ex-post evaluation of a rural road project in the Dominican

Republic in which it was found that the ex-ante windshield survey had correctly evaluated 6 out of 11 roads. This would make the reliability of the windshield survey about 0.55 and, assuming that the cost of the windshield survey was $40/km of road, the value for the efficiency parameter M would be 0.0026.

Rapid Rural Assessment

In the rapid rural assessment, a small multidisciplinary team of exports attempts to quantify the costs and benefits of the road project by extensive use of direct field observations, aerial surveys, interviews of key persons, including, of course, farmers of small properties, and the use of key indicators as proxies for economic variables, such as the quality of housing as a proxy for income (3). In the rapid rural assessment, in-depth surveys of production, income, and so forth, based on scientifically designed sampling plans and requiring detailed questionnaire surveys, are avoided.

In the calculation of the cost of this type of survey, it is assumed that the team consists of seven persons (team leader, two agronomists, two engineers, one sociologist, and one economist) and that two jeeps are used. About 60 days would be spent in the field and 40 days in the office. For a 500-km feeder-road project, the total cost of the evaluation would be about $200,000, again including per diem costs and domestic and international transportation, which makes the cost per kilometer about $400.

Though there have been a number of rapid rural appraisals in the recent past, the author knows of no case in which their accuracy has been evaluated. It is estimated, however, that their reliability would be between 70 and 80 percent and, assuming a cost of $400/km, the value of M would fall between 0.0013 and 0.0023.

In-Depth Survey

The in-depth survey represents the most intensive level of effort. A large multidisciplinary team spends a long time in the field collecting detailed data on crop types, cultivated areas, soil characteristics, yields, and the other information required to calculate the value added by the road project. Household interviews, for example, would be made to gather information on rural travel patterns. This type of survey would enable the most accurate determination of the economic feasibility of the road projects.

The team would consist of the same personnel as those for the rapid rural appraisal, with the addition of a statistician and 10 interviewers, and two more jeeps with drivers would be needed. They would spend about 5 months in the field and 3 months in the office, and the cost for the 500-km road survey would be about $500,000. On a per-kilometer basis the cost would be about $1,000.

In a comparative evaluation of selected highway projects performed by the World Bank and documented in an internal memo in 1974, it was found that of 15 road projects that had been identified as economically feasible in the ex-ante evaluation, three in retrospect turned out to be infeasible. These projects accounted for 14 percent of the investment. Furthermore, five of the projects (17 percent of the investment) had, in retrospect, a marginal rate of return. Hence, between 14 and 31 percent of the investment was in subnormal or marginal projects, and it may therefore be concluded that the gross reliability of the selection process was between 69 and 86 percent. This modest reliability is not, however, all due to weaknesses in the economic evaluation procedures. A major factor accounting for the infeasibility of some of the projects in this program was the large cost overruns caused by poor implementation of construction. Assuming that half of the unreliability was due to these cost overruns, the actual reliability of the evaluation procedures would be between 85 and 95 percent.

The level of effort devoted to the World Bank project evaluations was not documented, but it was estimated to fall between that of a rapid rural appraisal and an in-depth survey, at a cost of about $700/km. By applying the equation, it can be calculated that the value of M falls between 0.0017 and 0.0028. Another example is the series of ex-post evaluations of eight loans for rural roads carried out by the Inter-American Development Bank in 1980. Between 11 and 12 of the 14 road projects were correctly classified, giving a reliability between 0.79 and 0.86. As for the previous case, the level of effort devoted to the ex-ante evaluations is estimated at about $700/km and M therefore ranges between 0.00124 and 0.00182.

Value Added

The benefit/cost ratio of an economically feasible road project will, of course, be higher than that for an infeasible one. However, its average benefit/cost ratio will depend on a large number of factors, of which the two most important are the economic potential of the area within which the project is located and the condition of the road before improvement. Thus, for road projects that consist of upgrading an animal and pedestrian track in an agriculturally rich area that is only now being developed, the average benefit/cost ratio of the economically feasible projects may be quite high and may exceed 3.0. On the other hand, if the project consists of rehabilitating neglected roads in an area that has been under development for some time, and many of today's projects in the developing countries fall within this category, the average benefit/cost ratio of the economically feasible projects may fall between 2 and 3. Finally, a project consisting of improving a low-potential road located in, for example, the Sahel area of Africa may yield an average benefit/cost ratio of only about 1.5.

From a review of a number of road projects in South America and Asia that were completed during this decade, it was found that, on the average, an economically feasible project had a benefit/cost ratio of about 2.25, and the economically infeasible ones had a benefit/cost ratio of about 0.5. The projects consisted of rehabilitating roads that had seriously deteriorated because of lack of maintenance, and the lack of access resulting from the poor road conditions had supressed the development of agriculture in the regions served by the roads. Such road projects are common now in the developing countries, and in the application of the model in the next section, these roads will be taken to represent the nominal case.

APPLICATION OF THE MODEL

In this section the model will be used to develop an understanding of what the appropriate level of effort should be for feeder-road evaluations. Figure 1 shows the total value of the road construction program as a function of the level of effort devoted to the evaluation and as predicted by the model. The parameters used by the model in developing Figure 1 assume the nominal values derived in the section on estima-

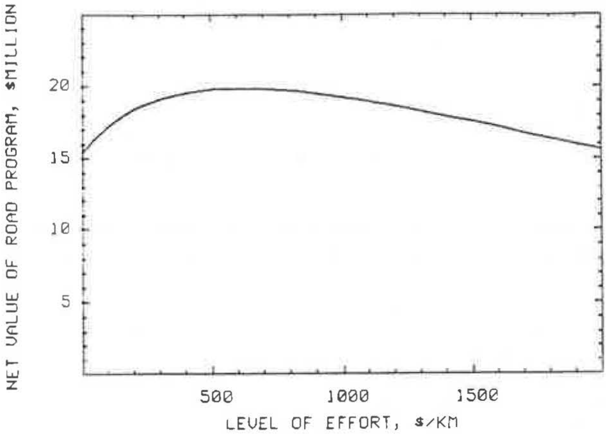

FIGURE 1 Nominal case.

tion of the parameters. These values, it will be recalled, are believed appropriate for current projects involving the rehabilitation of feeder roads that, through neglect of maintenance, are in bad condition and therefore carry little or no mechanized vehicle traffic. These values are as follows:

1. The probability that a road project on the candidate list is economically feasible (PG) is 0.7.
2. The efficiency (M) of the evaluation procedure is 0.002.
3. The average benefit/cost ratio of an economically feasible project (GS) is 2.25.
4. The average benefit/cost ratio of an economically infeasible project (BS) is 0.5.
5. The average construction cost of a project (the project is assumed to be 20 km long) (CC) is $10,000/km, and the total budget for road construction is $21 million.

The effect of deviations from these nominal values will be explored later.

As shown in Figure 1, the net value of the road program even with a zero level of evaluation effort is about $15 million. (As discussed earlier, the net value of the road program is equal to the total benefits generated by the program minus the construction cost and the evaluation cost.) As the level of effort increases, the net value of the program rises rapidly because the infeasible projects are being weeded out until a maximum of about $20 million is reached at a level of effort around $600/km. This is the optimum level of effort, and the reliability of the evaluation effort at that point is about 0.85. As the evaluation effort increases beyond that point, still more infeasible projects are being eliminated, but the additional cost of the evaluation starts to offset the gain in benefits from the larger proportion of feasible projects. Thus, the net value of the program gradually diminishes. And, at a level of effort of about $2,000/km, at which the reliability of the evaluation process should be about 0.99, the net value of the road program is again slightly above $15 million.

A numerical example is useful to illustrate the shape of the curve in Figure 1. Because the proportion of good projects on the candidate road list for the base case is 0.7, the zero level of effort (such as simply picking every other project on the list or choosing the projects by tossing a coin) will result in a set of constructed projects in which 70 percent are economically feasible and 30 percent are infeasible. Because the cost of evaluation was zero, the whole road budget ($21 million) can be used for construction at $200,000 per project. Thus, 105 projects can be constructed, of which 73.5 (70 percent) are economically feasible and 31.5 (30 percent) are infeasible. The benefits generated by the economically feasible projects will be 2.25 times their construction cost, $450,000 per project, or $33 million in total (2.25 x $200,000 x 73.5). The infeasible projects will contribute benefits of only 0.5 times their construction cost, $110,000 per project, or $3.15 million in total (0.5 x $200,000 x 31.5). The total net return of the road program will therefore be $33 million + $3.15 million - $21 million = $15.2 million as shown in Figure 1.

With high evaluation levels of effort of $2,000/km of road, the reliability of the selection effort will be practically perfect, and only economically feasible projects will be constructed. However, the cost of evaluation will be high. For every seven good projects that are evaluated and constructed, three infeasible ones are evaluated and eliminated. In effect, for every economically feasible project that is constructed, 1 3/7 of a project must be evaluated at a cost of $2,000/km. The effective construction cost of the economically feasible projects is therefore

$200,000 + 20 x 1 3/7 x $2,000 = $257,143.

Also, the number of economically feasible roads constructed is

$21 million/$257,143 = 81.66.

The net value of the road program therefore is

2.25 x $200,000 x 81.66 - $21 million = $15.7 million.

As shown in Figure 1, the value of the road program rises rapidly as the level of effort increases, until the optimum of about $19.8 million is reached. After that, the value diminishes gradually because of the excessive cost of evaluation. It is important to note that the curve is steeper on the left-hand side (the side of reduced level of effort) than it is on the right-hand side (the side of increased level of effort). This would indicate that, under the usual uncertainty faced when a project is planned, it is better to err on the side of too much effort on the evaluation. For example, as shown in Figure 1, the optimum level of effort is about $600/km of road. A decrease in this level of effort of $400 would reduce the net value of the program to $18,331 million, a reduction of 7.5 percent. However, increasing the level of effort by $400/km would reduce the value of the road program to $19.17 million, a reduction of only 3.3 percent.

Figure 2 shows that with more efficient evaluation techniques (M = 0.005) so that a higher reliability of classifying a candidate road is achieved at a given cost, the optimum level of evaluation effort can be reduced to $400/km. (For the nominal case, as discussed previously, the optimum level of effort was $600/km.) In addition, more efficient evaluation techniques also increase the maximum possible value of the road project to about $22.6 million; this is about 14 percent above the $19.8 million value for the nominal case. It can also be seen that, as for the nominal case, the curve is steeper to the left of the optimum level of evaluation effort than it is to the right. Again, this means that it pays to err on the side of too much effort on the evaluation rather than too little. For example, decreasing the level of effort by $400/km from the optimum would reduce the value of the road program to about $15 million, a reduction of about 33 percent. Increasing

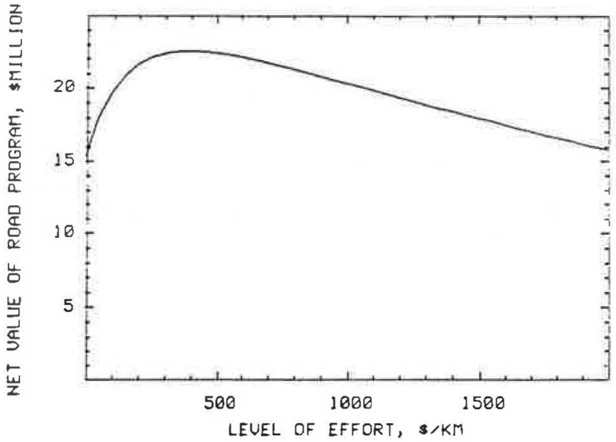

FIGURE 2 More efficient evaluation.

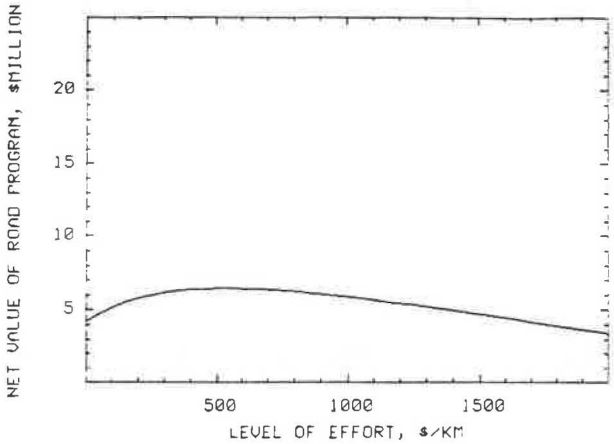

FIGURE 3 Low-potential projects.

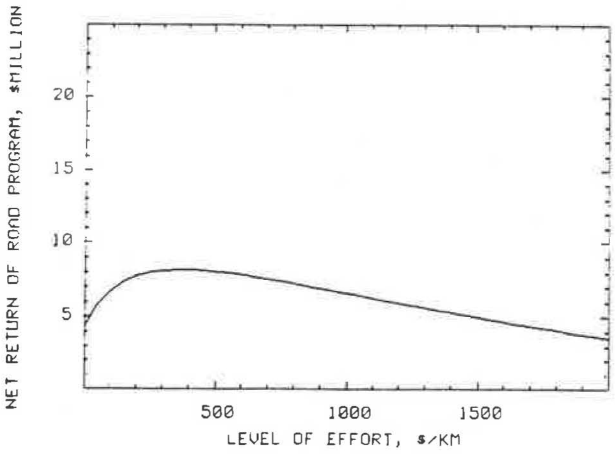

FIGURE 4 Efficient evaluation of low-potential projects.

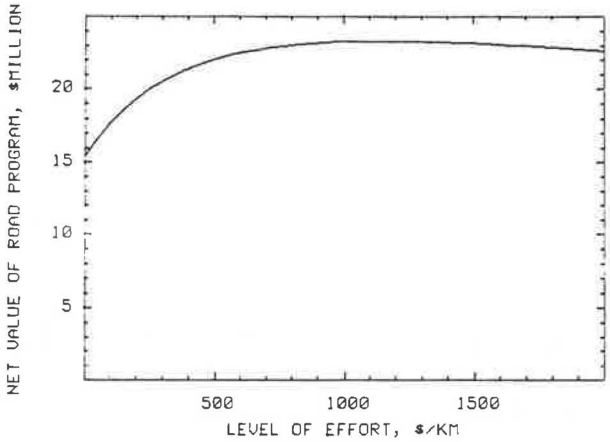

FIGURE 5 High-cost projects.

the level of effort by $400/km would reduce the value of the road program to about $21 million, a reduction of only 6 percent.

Figure 3 is indicative of low-potential projects, such as those in sparsely populated areas with low agricultural potential; the average benefit/cost ratio of the economically feasible projects in this case was assumed to be 1.5. The figure shows that the optimum level of evaluation effort is about $500/km. As expected for such projects, however, the maximum value of the road program is only $6.5 million, far below the $20 million or so that can be realized from the more productive projects.

The reason for the lower level of effort for low-potential projects (assuming the same construction cost and evaluation efficiency) is the proportionally lower return of these projects compared with the cost of evaluation and construction.

Again, it can be seen that it is better to err on the high side of evaluation effort than on the low side. To illustrate, a reduction of evaluation effort by $400/km will reduce the value of the road program to $5.2 million, a reduction of 20 percent. But an increase in effort of $400/km will reduce the value of the road program to $6 million, a reduction of only about 6 percent.

Figure 4 shows that, when low-potential projects are involved, improving the efficiency of the evaluation ($M = 0.005$) will substantially increase the net value of the road program (from $6.5 to $8.1 million, a 25 percent increase). The new optimum level of effort is $400/km, or $100 less than for the case with less efficient evaluation.

It will be recalled that increasing the evaluation efficiency by the same amount for the nominal projects increased the net value of the road program by only 14 percent. Thus, it can tentatively be concluded (clearly, more research is warranted in this area) that improving the skills of evaluation teams becomes even more important when low-potential projects are involved.

Figure 5 shows the case for the high-cost projects; these are projects in which the improvement cost is $35,000/km of road. This would be an unusually high cost for a feeder-road improvement project and is presented only to illustrate the impact of higher construction costs on the optimum level of effort. The optimum level of effort for such high-cost projects would be about $1,100/km, a substantial increase from the $600/km for the nominal case. But the net value of the road program is even less sensitive to the optimum level of effort than it was for the previous cases. To illustrate, a decrease of $400/km in the level of effort would cause the net return to drop from $23.3 million for the optimum level of effort to $22.8 million, a reduction of only 2 percent. Increasing the level of effort by $400/km would reduce the net value to $23.1 million, a reduction of less than 1 percent. In fact, the curve is so flat around the optimum that a level of effort corresponding to the nominal case, $600/km, would reduce the net value of the road program by only about 3.5 percent.

In summary, it has been seen that, around the optimum, the net value of a road program is remarkably insensitive to the level of effort. In general, for road improvement projects that are of fairly low cost, such as around $10,000/km, the optimum level of effort will fall between $400/km and $600/km; this is on or slightly above the rapid-rural-appraisal level of effort. For more expensive road projects, such as those costing around $35,000/km, the optimum level of effort is about $1,100/km and comparable to an in-depth survey of level of effort. However, for the high-cost projects, the value of the road program is so insensitive to the level of effort that the use of rapid rural appraisal techniques would result in only a minor reduction in the net value of the road program.

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Recent Developments in Rural Road Design in Australia

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ABSTRACT

Two-lane roads make up the bulk of the rural road system in Australia and carry most of the travel between major cities. A number of developments in the geometric design of these roads are discussed, with particular reference to the contributions made by the Australian Road Research Board. Some of the major changes have been a greater emphasis on alignment consistency, the growing use of auxiliary lanes, and the move toward partial sealing of shoulders. Some details of new design guidelines are presented. Partial shoulder sealing was introduced primarily to reduce maintenance costs but has since been found to have safety and operational benefits. A survey of shoulder use has provided information on the probability of meeting stopped vehicles on the roadside and given some recommendations on shoulder and rest area design. Traffic simulation has been used to evaluate alternative road improvement strategies, including alignment changes and the use of auxiliary lanes. The TRARR simulation model is now being used by several state road authorities for planning and investigation studies. A consideration of accidents and road geometry is an underlying theme of the research on all of these topics.

Approaches to the geometric design of rural roads in Australia have undergone a number of changes in recent years. The emphasis has shifted from the rigid application of design standards to a greater awareness of the specific objectives for a given project and the alternative methods for achieving these. Many design standards have been critically reviewed, and particular attention has been paid to the cost-effectiveness of alternative road improvement options.

A number of these changes are discussed, with particular reference to the contributions made by the Australian Road Research Board (ARRB) and the continuing research in this area. For simplicity, only the geometric aspects of road design for isolated road sections away from intersections and towns are considered.

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