resentative of recent construction activity. This process of data collection and reanalysis will be repeated periodically.

CONCLUSION

Analysis has shown that aggregate payout on construction contracts can be adequately predicted given improved forecasting techniques and information management. The forecasting technique described in this paper requires information only on the type of construction, the road system, the size of the project, and its actual or prospective start date to make estimates of payout that are up to 93 percent accurate. This degree of accuracy can be attained by frequent and timely updates of the information in the forecasting data base on contracts let and on contracts on the advertisement schedule. Because payments to construction contractors are a major cash flow item for the Virginia Department of Highways and Transportation, as they are in many states, it is anticipated that better forecasts of construction payout will be a valuable aid in the budgetary process.

Setting Priorities of Highway Projects by Successive Subsetting Technique

MARK D. HARNESS and KUMARES C. SINHA

ABSTRACT

The development of a technique that can be used to set priorities within a given work category of highway improvement projects is described. After impact categories have been developed, respective priority evaluation measures assess the importance of specific projects within each impact category. The proposed technique of successive subsetting combines the impacts of each candidate project in a work category to determine which projects should be implemented for a given budget. A sample problem consisting of a group of bridge replacement projects is presented to illustrate the application of the technique.

Traditional approaches--weighting factors and developing combined scores of sufficiency ratings--to setting priorities among highway projects have the serious drawback of masking the importance of individual factors. The use of such approaches does not always produce an optimal set of projects, nor can specific reasons be given for selection choices. In the face of increasing highway construction costs and an increasing backlog of improvement projects, greater efficiency in selecting projects for implementation, as well as provision for the defense of the set of projects selected for implementation, must be established.

In this study it is assumed that projects have already been established for given needs. It is also assumed that the best alternative within each project proposal for a particular location has already been chosen. Under these assumptions, a priority-setting technique has been developed that can aid in the choice of the set of projects for implementation within a given work category. This study was sponsored by the Indiana Department of Highways (IDOH) and has been developed for use within its planning division.

HIGHWAY IMPROVEMENT IMPACT CATEGORIES AND PRIORITY EVALUATION MEASURES

When priorities are determined for individual projects within a work category or functional classification, significant types of impacts must be determined. After this, methods for measuring the extent of these impacts must be developed to describe the importance of each project. An impact category is defined as the general impact type that has a specific importance level within a work category. A priority evaluation measure is the value that represents the importance of a project with respect to a given impact type.

SUCCESSIVE SUBSETTING

The major problem in using a priority-setting technique is that available data are mostly subjective and have a low degree of accuracy. Consequently, in the proposed technique, it is assumed that impacts of highway improvements cannot be measured precisely and that, if they can be, the limits of accuracy are quite large. It is assumed that all projects in each impact category can be lumped only approximately into a small number of groups. The members of each group will then have about the same impact value or priority evaluation measure.

The key to this technique is that each smaller group or subset may also be divided into additional smaller groups using different evaluation criteria. A representation of the successive subsetting operations is shown in Figure 1. As a result, although the first separation of projects may produce only, for example, five groups, the second round of subsetting may produce 25 groups (or five groups of five). This procedure may be used as many times as there are impact categories. Consequently, a group of projects separated into three subgroups five times will produce 243 subsets. Five groups divided five times will produce 3,125 subsets.

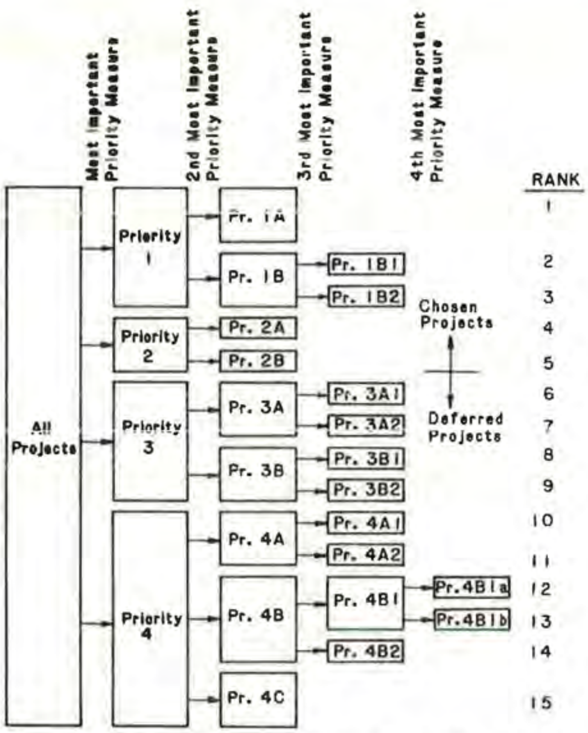

FIGURE 1 Flow chart of successive subsetting technique.

Use of this technique allows a large number of projects to be ranked in a small number of steps using data that need not be highly accurate. In addition, only a few impact measurements are necessary for each project proposed. This means data requirements can be substantially reduced.

REQUIREMENTS OF SUCCESSIVE SUBSETTING TECHNIQUE

Instead of determining the numerical priorities for each type of impact, the relative importance of different types of impact needs to be ranked. Then, for each budgeting or work category, the projects must be split into several subgroups according to the most important priority measure. Each subgroup must again be separated into more subsets using the second most important priority evaluation measure. This continues until all projects belong in a separate subset.

For a single subsetting step, the decision maker must have an understanding of the degree of accuracy of the priority evaluation measures to be used. Subgrouping should be done only if there is a smaller degree of difference between values. However, rather than using precise statistical methods to determine which values are statistically different, the user can visually observe the distribution of the values and make approximations between different values. Then, by repeating this step using other priority evaluation measures for each of the smaller subgroups, each category may be subdivided a number of times to produce a finely separated distribution of all projects by rank.

Before the impact categories can be ranked, the decision maker must clearly understand the relative importance of the impact categories and their respective priority evaluation measures. The first subsetting step has the greatest influence on what priority a given project will have. This is because, in the second subsetting step, in the absence of the use of any trade-off curves, the second most important priority evaluation measure will affect only the ranking of projects within the original subgroups. For example, a project located in the second most important subgroup in the first subsetting step cannot move up to the most important subgroup.

If the relative importance of impact categories is clearly distinguished, that is, if each priority evaluation measure clearly has a greater significance than the next most important measure, the priority evaluation measures may be ranked and applied successively to produce individual subsets for all the projects.

However, if some priority evaluation measures have similar importance levels, either within or between different impact categories, trade-off curves must be developed to combine these measures. Figure 2 shows how two priority evaluation measures may be combined to subgroup projects. The relative importance of the two priority evaluation measures is reflected in the slope of the lines separating the subgroups.

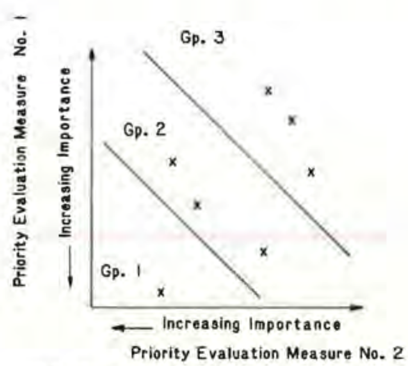

FIGURE 2 Single subgrouping of projects using two priority evaluation measures.

If more than two priority evaluation measures have about the same level of significance, they may be combined as shown in Figure 3. Here the resulting subgroupings for the first two measures are traded off against a third measure. The result of this sub-

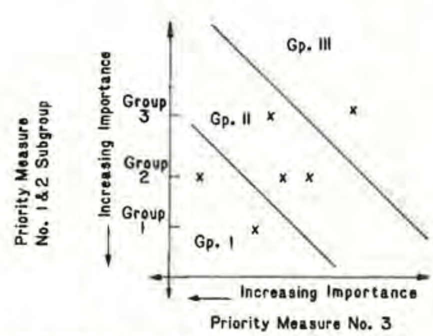

FIGURE 3 Single subgrouping of projects using three priority evaluation measures.

grouping step may then be traded off with further priority evaluation measures.

However, when two or more measures are traded off, they combine to produce only one subgrouping step. Consequently, if a large number of projects must have their priorities determined, this may be a disadvantage. It is possible, however, to offset this small number of subsetting steps by increasing the number of groups made in each subsetting step. Again, however, the accuracy of the data must not be overestimated.

One advantage of this priority-setting method is that sets that have no subsets with more than one project do not have to be further subdivided. Only those groups having projects with very similar priority evaluation measure values must be subdivided using the increasingly less significant impact categories.

In addition, if the overall budget level is known, subsetting of projects need be applied only in the groups where the cutoff point lies between programmed and deferred projects. A group does not need to be subdivided if all of the projects in it will be selected. However, for the purposes of this study, all of the projects will be ranked in case changes in budget level are made.

SUMMARY OF STEPS

The general steps involved in the application of the proposed technique are

1. List priority measures in order of decreasing significance combining those of nearly equal importance.
2. Plot projects by their most important priority evaluation measure or measures.
3. Separate projects into subgroups.
4. For each subgroup, repeat steps 2 and 3 using the next least important priority evaluation measures until each project is in its own subgroup.
5. Rank projects in decreasing order of priority.
6. Select projects for implementation in order of rank until the budget for the given period has been met.

APPLICATION OF THE PROPOSED TECHNIQUE

This section describes the application of the successive subsetting technique to the bridge replacement work category using a set of 22 proposed bridge replacement projects.

Bridge inventory ratings for each of the 22 bridges were collected. These were rated in accordance with the FHWA Bridge Inventory and Appraisal Manual (1). The key for the subjective condition ratings required by this manual is given in Table 1.

TABLE 1 Key for Subjective Condition Ratings *(1)*

Numerical Rating	Bridge Condition
9	New
8	Good
7	Good with minor maintenance needed
6	Fair with major maintenance needed
5	Fair with minor rehabilitation needed
4	Marginal with major rehabilitation needed
3	Poor with rehabilitation or repair needed
2	Critical with need to close and rehabilitation or repair needed
1	Critical, is closed and may not be repairable
0	Critical, is closed and beyond repair

Bridge replacement projects may be evaluated using four major impact categories: the cost to the highway department to replace the bridge, the physical condition of the present bridge, the traffic volume using the bridge, and the safety of persons driving over the bridge (see Table 2).

TABLE 2 Relative Importance of Bridge Replacement Priority Evaluation Measures

Rank	Impact Category	Priority Evaluation Measure
1	Physical condition	Minimum of superstructure condition and substructure condition
2	Physical condition	Remaining life
3	Traffic safety	Deck width
4	Traffic safety	Road narrowing on bridge
5	Service and highway department cost	ADT ÷ state share of construction cost
6	Traffic safety	Approach alignment
7	Traffic safety	Deck pavement condition
8	Location	Road classification

Physical Condition

The most important factor in bridge replacements is the physical condition of the existing bridge. This measures the ability of a bridge to avoid a catastrophic failure.

Because IDOH bridge data are gathered according to federal guidelines (1), priority evaluation measures available for this impact category are the subjective measures of substructure condition, superstructure condition, and remaining life.

Theoretically, the life of a bridge will end when either the substructure or the superstructrue becomes so poor that the bridge must be closed to prevent its collapse while someone is using the structure. Therefore, ideally the remaining life value will be proportional to the minimum of the substructure and superstructure condition values. However, this is not always true because of the subjective nature of the measurement of these values.

Instead of using remaining life as the sole measure of physical condition, both the minimum of the two condition ratings and the remaining life may be used. These may be combined by plotting the minimum of the superstructure and the substructure ratings against the remaining life value.

The 22 projects were subdivided into eight groups according to physical condition, as shown in Figure 4. The numbers in the figure indicate project numbers in the 1982-1984 IDOH work program (2). It can be seen that a remaining life of 5 years is approximately equivalent to a minimum superstructure or substructure condition rating of 3. Likewise, 20 years of remaining life correspond to a minimum condition of 7. Therefore, projects that lie perpendicular to the values of the linear relationship should be placed in the same subgroup. This should best reconcile the discrepancy for projects having remaining life and minimum condition values that do not fall on the line. Therefore, projects having condition ratings of 3 and a remaining life of 5 years were placed in the most important category (group A). The next most important group consisted of the projects having conditions of 4 and lives of 5 years and the project having a condition of 3 and a life of 10 years. The five projects in this category (group B) were deemed to be in approximately the same physical condition. The remaining 13 projects were combined into six groups in the same manner. Of the eight groups, groups F and H needed no further subdivision.

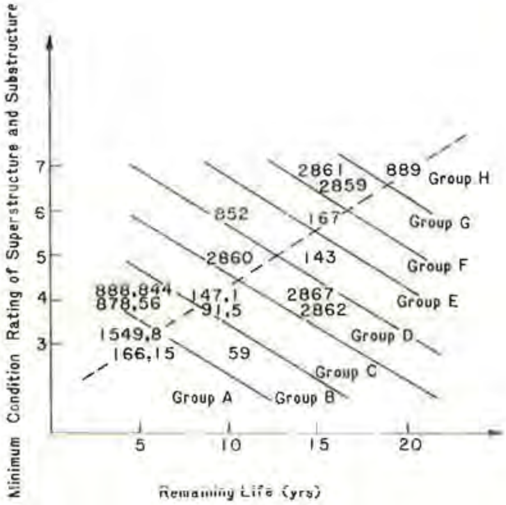

FIGURE 4 First subgrouping step for sample bridge replacement problem.

Traffic Safety

The second most important aspect in determining bridge replacement priorities is traffic safety. The best measurement of this is the accident rate on the bridge. However, because this was not available, values of approach alignment condition, deck width, road narrowing on the bridge, and deck pavement condition from the bridge sufficiency rating data were used (see Table 2). Road narrowing was defined as the bridge deck pavement width minus the roadway pavement width.

Assuming deck width is the most significant priority evaluation measure and road narrowing is the next most significant, each subgroup from the physical condition subsetting step may be subdivided into several subsets.

The remaining six groups were subdivided according to safety as shown in Figure 5. In this subsetting step, deck width and road narrowing represent two different types of safety hazards, but deck width was determined to have greater influence on priority than does road narrowing. An example of this is that even though project 8 had a pavement width 5 feet narrower on the bridge than on the approach and project 1549 was 5 feet wider on the bridge, both projects were placed in the same safety subgroup because both had deck widths of about 35 feet.

In drawing the lines separating the subgroups, the decision maker must decide in each case how much need, according to the narrowing evaluation measure, is required before a project may be advanced to a group having greater need according to the deck width evaluation measure. In all six classes (see Figure 5) it may be seen that the slope of the lines separating the subgroups could have been vertical without changing the membership of each subgroup. However, if project 56 of class B had had the same deck width but a very low road narrowing value, the line separating the groups could have been drawn further to the right to include this project in group B.a. Of these subgroups, only six needed further subdividing.

Service and Highway Department Cost

The next most important impact group for bridge replacements is the cost to replace the bridge. The level of service provided by the bridge is also important (see Table 2). Because these two groups have approximately the same level of importance, they may be combined into a single subsetting step. The highway department cost may be measured by either the total right-of-way and capital cost of the bridge or the share of this cost that the state highway department must pay. The latter method will give higher priority to bridges having greater amounts of federal funding. The level of service provided by

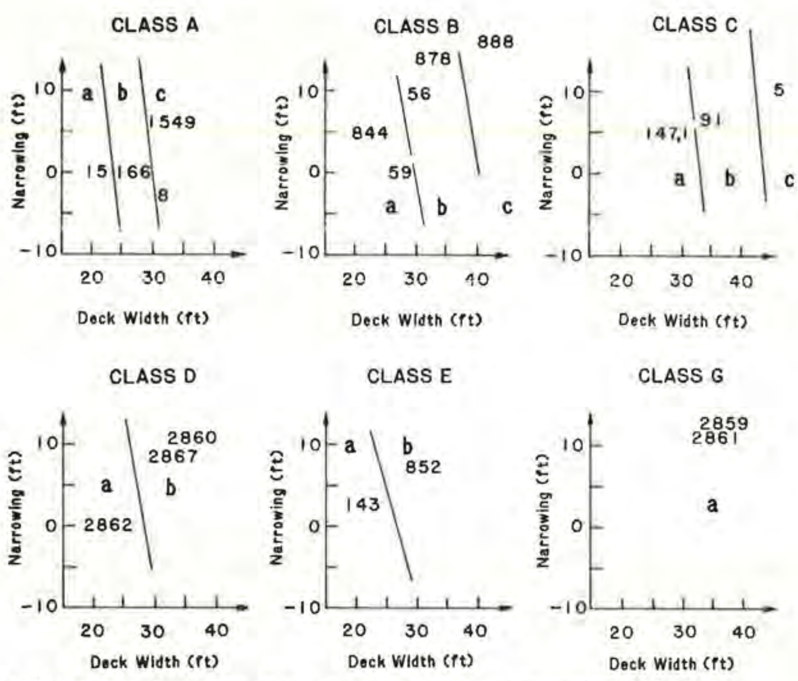

FIGURE 5 Subgrouping by safety priority evaluation measures within each condition category.

the bridge may be easily measured by the ADT on the roadway that the bridge serves.

Instead of using a trade-off curve to combine the service and cost measures, a logical measure combining these two measures would be the service-to-cost ratio:

Service/cost ratio = ADT/construction cost

This value shows the relative number of vehicles that would be served per dollar of construction cost. A larger value would represent a more cost-effective project. These values may be used to subdivide the subgroups that result from the previous traffic safety subsetting step.

Subdivision according to the service-to-cost ratio is given in Table 3. Here groups A.c., B.a., B.b., C.a., D.b., and G.a. had their remaining projects ranked. Because each of these groups had only two projects in them, the project with the greater service-to-cost ratio was given the higher priority.

TABLE 3 Subgrouping by Service-to-Cost Ratio for Remaining Safety Categories

Class	Project No.	Service ÷ Cost	Rank
A.c.	1549	163	i
	8	22	ii
B.a.	844	21	i
	59	21	i
B.b.	878	10	ii
	56	40	i
C.a.	147	81	i
	1	37	ii
D.b.	2860	52	ii
	2867	162	i
G.a.	2861	99	i
	2859	45	ii

However, in group B.a., both projects had the same service-to-cost ratio. Therefore, only one subgroup (group B.a.i.) needed further subdividing. This was done according to the next important priority measure, approach alignment, which is another safety measure.

Project No.	Approach Alignment	Rank
844	8	2
59	4	1

Project Ranking

Now each project must be ranked against each other project. This may be done by listing the total set of projects in descending order of importance. For example, if only the first three impact categories were used, the most important project would be in the most important condition group, the most important safety subgroup, and the most important service-to-cost subgroup. Finally, after each project has been ranked, projects may be chosen for implementation during the budget period until the total budget level has been met.

The projects were ranked, and the appropriate projects chosen for implementation are given in Table 4. The total budget considered for the sample bridge replacement problem was $1,025,000.

RESULTS OF THE SAMPLE PROBLEM

The technique used for the bridge replacement problem has resulted in a ranking of the 22 candidate projects, seven of which were chosen for implementation within a 2-year budgeting period. Because of the nature of the subsetting technique, these seven projects were in the worst physical condition of the projects considered.

TABLE 4 Final Rankings and Project Choices for Implementation

Rank	Project No.	Project Cost[a]	Available Budget[a]	Overall Condition Estimate
Chosen				
A.a.	15	136	1,025	–
A.b.	166	166	889	Very poor
A.c.i.	1549	19	723	Poor
A.c.ii.	8	45	704	Poor
B.a.i.1	59	302	659	Poor
B.a.i.2	844	57	357	Poor
B.b.i.	56	237	300	Poor
Deferred				
B.b.ii	878	122	63	Poor
B.c.	888			Poor
C.a.i.	147			Fair
C.a.ii.	1			Fair
C.b.	91			Fair
C.c.	5			Fair
D.a.	2862			–
D.b.i.	2867			–
D.b.ii.	2860			Poor[b]
E.a.	143			Fair
E.b.	852			Fair
F.	167			Good
G.a.i.	2861			Good
G.a.ii.	2859			Good
H.	889			Very good

Note: Dashes = not done.
[a]In thousands of dollars.
[b]Subjective rating error.

For the 2-year budgeting period, the bridges in the worst physical condition subgroup and three of the five bridges in the second worst condition subgroup were selected. All three of the projects in the second worst condition subgroup had low safety ratings. From the position of these bridges in Figure 4 it can be seen that all seven projects chosen had a minimum superstructure or substructure condition of 4 or less and a remaining life of 10 years or less. In addition, all seven projects had a road narrowing value of 10 ft or less, and six had a deck width of 30 ft or less. The distribution of the priority evaluation measures for all the proposed projects is shown in Figure 6.

Obviously, the categories with the greatest need are substructure condition, superstructure condition, and remaining life. The distribution of chosen projects is also concentrated on the right side in the deck width and road narrowing categories. The categories of state share of construction cost, deck pavement condition, approach alignment condition, and ADT are relatively uniform for the chosen projects. This is because of the relatively lower degree of importance placed on these priority evaluation measures.

CONCLUSIONS

The successive subsetting technique has been developed to set priorities for highway improvement projects within work categories. This can be done using fairly inaccurate and subjective data. In addition, the technique is very flexible and simple to use. A computer is not necessary. Exact measures of importance of different impact types do not need to be known in advance. The specific grouping of projects

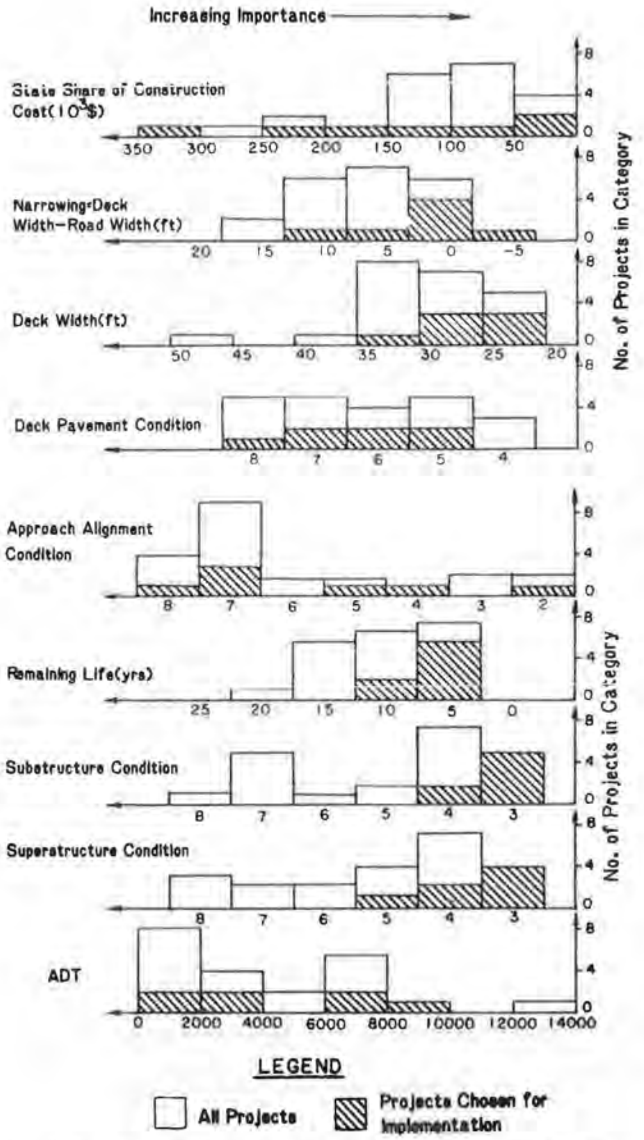

FIGURE 6 Distribution of priority evaluation measures for all sample bridge replacement projects and for those chosen for implementation.

is determined after individual values for priority evaluation measures are plotted and their distribution over all projects is known. Then the projects must be separated into groups having similar priority evaluation measures. The decision maker needs only a general understanding of how the data were gathered and of the limits of accuracy of the individual measurements.

One problem that may develop using this technique is that for work categories that have a large number of projects it may be difficult to separate each project into its own group. This problem may be resolved in several ways. Either more priority evaluation measures may be applied to produce a greater number of subsetting steps or a greater number of subgroups may be made in each subsetting step.

Because the relative priorities of each project are ranked using the subsetting technique, it is easy to determine which projects should be added or deleted if there are adjustments to the overall budget level after the program has been developed.

An important aspect of the subsetting technique is that it may also reveal which projects may not be in the appropriate work category. For instance, several projects in the bridge replacement sample problem were determined to be in relatively good condition. It would be better if these projects could be placed in a less costly work category. For example, bridges in relatively good condition could be moved from the bridge replacement category to the bridge maintenance category. This recategorizing of projects could reduce overall highway improvement costs as well as the number of backlogged projects in some categories. Less important projects could also be placed in job categories requiring less extensive work. A bridge that might have a relatively low priority in a bridge replacement category might receive a relatively high priority in a bridge rehabilitation or bridge maintenance category.

This technique can isolate projects that have data discrepancies. Projects that have both high and low ratings within the same impact category should be re-examined to determine the true condition of the existing structure or roadway section.

The simplicity and straightforwardness of this procedure should make it appropriate for use by both more and less technically trained personnel. As a result, it could be used at both state and local levels of jurisdiction as well as at central and district levels of state highway offices. The graphic format should make it easily understandable by the layman.

In addition, the flexibility of this technique should make it usable as both a manual and a computerized procedure. If computerized, it would be most useful to input trade-off curves after the distributions of individual project priority evaluation measures have been plotted.

ACKNOWLEDGMENTS

The research reported in this paper was sponsored by the Joint Highway Research Project of Purdue University and the Indiana Department of Highways. The assistance of Larry Scott and James Barr of the Indiana Department of Highways is gratefully acknowledged. The authors are, however, solely responsible for the contents of this paper.

REFERENCES

1. Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges. FHWA, U.S. Department of Transportation, 1979.
2. Biennial Highway Improvement Program: July 1982 to June 1984. Indiana Department of Highways, Indianapolis, Ind., 1982.
