Decision-Maker-Defined Cost-Effectiveness Framework for Highway Programming

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Federal regulations that specify the development of the transportation improvement program charge metropolitan planning organizations with responsibility for establishing a forum for cooperative transportation decision making. This paper describes an effort by the Chicago Area Transportation Study to perform that role. It focuses on the development of a simple linear weighting scheme for use in ranking federal-aid urban system highway projects for inclusion in the transportation improvement program for DuPage County, Illinois. This approach was developed in close working relationship with local decision makers, who participated in the selection of measures of effectiveness, the weighting of those measures, and the definition of the overall scheme. The results of the method, which combined both traffic and environmental measures for two points in time, were provided to decision makers as a basis for choice rather than as a rule for decision making. The success of the effort was measured by the correspondence between the analytic ranking of projects and the transportation improvement program ultimately chosen by local officials.

Recent federal regulations that define the requirement for the transportation improvement program (TIP) mandate metropolitan planning organizations (MPOs) to function as "forums for cooperative decision-making by principal elected officials. . . . " (1). The development of the transportation improvement program as a major product of the planning process focuses planning (and MPOs) on decision-making processes by calling for planning organizations to be more supportive of decision making than in the past when their products were plans with a long-range focus rather than immediate investment programs.

The role of the MPO is to guide the development of the processes of choice from those based largely on political negotiations to decision making based on objective consideration of needs, benefits, and costs while remaining politically responsive to the preferences and desires of citizens and interest groups. Working this closely with decision makers requires the development of interactive planning and analysis processes that are both sensitive to decision makers' needs and capabilities and technically sound. In developing such tools, compromises must be made, the ultimate objective being to provide technical support to an effective decision-making process. Thus, decisions and decision making must be the ultimate focus of the development of tools in the practical environment of the MPO (2).

This paper documents an evaluation procedure developed to select federal-aid urban system (FAUS) highway projects for inclusion in the annual element of the TIP in DuPage County, Illinois. This work was conducted by the Chicago Area Transportation Study (CATS) in cooperation with the Council of Mayors and City Managers of DuPage County, which is the principal political decision-making unit concerned with the investment of FAUS funds in the county. Although the methodology itself was tailored to meet the needs and desires of the DuPage County Transportation Subcommittee (TSC) of the subregional council, the approach itself may be useful in other programming contexts.

The charge to CATS in the development of this method was to create a procedure to produce a realistic ranking of highway projects selected from a larger list of locally generated projects, based on objective measures of the worthiness of each project, the readiness of each project for immediate implementation, and community values as reflected by the preferences of local officials. It was understood that this ranking procedure would be applied in support of decision-making processes and that the ultimate TIP would be chosen by decision makers; the ranking procedure would thus be an input to the overall decision-making process and might even help structure negotiations among local officials. It was not to be viewed as an inflexible decision rule, however.

Before the development and adoption of a relatively objective strategy of project evaluation, the TSC selected projects through a relatively unstructured process of negotiations. The first projects suggested for implementation were typically the first projects to be funded, and the readiness of a project for immediate implementation was sometimes more important in the choice process than the worthiness of the project itself. Such an approach was reasonable when the number of projects submitted was within the budget allocated for the FAUS program in the county. However, when the total costs of the suggested projects exceeded available capital, this unstructured negotiation process became more difficult to use. Therefore, the TSC sought a new evaluation and choice process based more directly on measures of project worthiness. It was important for the method to be objective to avoid claims of favoritism and provide clear justification for programming decisions.

THE DECISION-MAKING ENVIRONMENT

The Council of Mayors and Managers of DuPage County is a subregional forum for decision making regarding FAUS funds allocated to the county level. This council retains decision-making authority, but the principal tasks associated with transportation investment choices are delegated to the TSC, which is made up of some city managers, public works directors, and principal traffic engineers from various communities. There are 12 members on this subcommittee. These individuals have a limited time budget and must annually examine 20 or more highway projects under this program and compare and evaluate them for the purpose of making a choice.

Subcommittee members have varied backgrounds, and all were not well versed in transportation planning. Each participant does have detailed knowledge of some of the candidate projects and at least a general knowledge of the others. This allows the application of personal experience and expertise in the choice of investment alternatives. Participants are generally aware of the unique aspects of proposed projects that are not easily accommodated in an objective evaluation process. For example, a bridge that has deteriorated to the point where it has become a safety problem can easily be accepted as a high priority for maintenance or improvement even without sophisticated benefit measures.

Still, given budget limitations, it is important to provide this decision-making group with some objective guidance for project ranking and selection of a TIP. The technique discussed below was developed to provide a high level of decision-maker participation in the evaluation process, to accommodate objective measures of project worth as well as other subjective and more political factors that were clearly important to the choice, and to encourage a detailed and structured discussion of alternatives within the decision-making body.

COST-EFFECTIVENESS EVALUATION

The approach adopted was based on the philosophy of cost-effectiveness analysis (3). The effectiveness of each alternative is characterized by a number of measures of effectiveness chosen as relevant to the local situation. An effectiveness index is related to project cost, and the result is used to create an initial ranking. The decision on what is cost-effective and which projects are to be included in the final improvement program is made by decision-makers and is clearly subjective and open to negotiation. The value of this general approach is in its ability to compare a variety of project types in a number of important dimensions and to provide guidance to decision makers while not making the decision itself.

The method begins with the selection of a set of measures of effectiveness or criteria that are used to characterize the alternative projects. These were generated through an interactive process that involved members of the TSC and the CATS technical staff. Discussions of issues and factors to be measured (and specific measures themselves) were held in small groups of three or four subcommittee members. The meetings were conducted both to identify the factors of importance to the subcommittee and to introduce participants to various measures of effectiveness that might prove to be relevant. The result of these small meetings was a broad set of measures, a number of which could not be put in operation because they were either ill-defined or too costly. In the second stage of the measure-development process, this broad set of measures was examined critically by the technical staff, and definitions were sharpened where necessary. The set of measures finally selected by the TSC was as follows:

1. Change in peak-hour travel time,
2. Change in equivalent property damage (EPD) rate of accidents,
3. Change in average daily congestion (volume/capacity ratio),
4. Change in off-peak daily travel time,
5. Change in noise pollution,
6. Change in air pollution, and
7. Number of dwelling units taken.

Change refers to the difference between the build and no-build cases for the measure. Effectiveness was thus characterized as reductions of various negative attributes. The measures were applied to two distinct time periods: the present (actually 1975 because of data limitations) and 1985. This provides an evaluation of both the immediate and medium-range effects of the proposed project. Decision makers chose to use both of these time points in their evaluation process; continuous time streams were not considered because of the problems associated both with treating them directly and with aggregating them to some "present value."

This set of measures is the result of interaction and compromise among decision makers and the technical staff. It is clear that there is a high level of intercorrelation among the measures, particularly measures 1 and 3 but also measures 2, 4, 5, and 6; this amounts to multiple counting of some effects of projects. A conceptually more sound approach might call for a reduced set of measures and an associated shift in the aggregation weights. But these measures reflect the impact categories of direct concern to the decision makers, and thus the choice was made to compromise in the direction of decision-maker interests to ensure their involvement with the expectation that a modest success at this level might provide an opportunity for further improvement of the methodology at a later date.

AGGREGATION OF MEASURES

The technical staff proposed to work with a matrix display format that illustrated the disaggregate effectiveness dimensions and costs of the alternatives and highlighted the trade-offs among them. Although aggregation of the effectiveness measures simplifies the choice process, it covers up important information about the specific attributes of alternatives, and it assumes that appropriate and stable weights can be derived.

The decision makers, however, expressed a preference for a simple linear weighting scheme to aggregate effectiveness. Arguments against weighting in general, and linear weighting in particular, were rejected in favor of the simpler approach. Since the decision makers were relatively familiar with the alternatives and their attributes and since the ultimate choice of projects for implementation was to be made by using the evaluation scheme along with other information and judgment, it was felt reasonable to adopt this simplified linear approach. The scheme was not a decision rule but merely a decision aid.

Weights or priorities associated with each of the measures were constructed from information provided by the participating decision makers by using a Delphi process (4). Delphic voting ensured that all members of the subcommittee had an equal opportunity to influence the outcome; in an open voting situation, it is more likely that dominant individuals would be able to have an inordinately large influence on the outcome. Delphi has also been shown to be an effective consensus-building technique within a group that has divergent interests (5). It tends either to move opinions toward a fairly strong consensus or to polarize them and thus to isolate areas of disagreement on which further, open discussion is warranted. Delphi also provided the possibility for individual participants to indicate a lack of understanding of one or more of the measures and to get an explanation to clarify those measures without having to admit to a problem within the group as a whole.

The Delphi weighting process was conducted over three rounds by using mail-back forms (Figure 1). A five-point semantic scale was used, and participants were provided with a graphical description of voting in the previous round as well as a personalized indication of how they had voted previously. The opportunity was then provided for a new, modified vote by each participant. Throughout this process, close personal contacts were maintained between the technical staff and the decision makers. This was accomplished by telephone calls and personal visits to clarify the procedure and the measures and to help participants respond to the questionnaires correctly. A secondary benefit of these close contacts was the establishment of a strong relation between the technical staff and the decision makers, which facilitated the successful implementation of the overall methodology.

A comparison of the group average weights for the various measures between rounds 1 and 4 indicates that there was a general trend toward convergence on a mean value for most measures. Average weights for each of the rounds on each of the measures are given in Table 1 along with the variance associated with each weight.

The data given in Table 1 show that the participants generally valued effectiveness in 1985 as more important than immediate effectiveness. That this is contrary to the economic theory of discounting was pointed out to members of the TSC (6). Their rationale was based on the observation that DuPage County is one of the most rapidly growing parts of the Chicago metropolitan area. They perceived their role as that of creating a transportation system to meet future needs when the population of the county would be larger and development more diverse.

For similar reasons, participants felt that environmental impact measures were generally not as important as traffic-related impacts. Therefore, they adopted a weighting structure that separated the two types of measures and placed a heavier weight on traffic measures with respect to environmental measures in a ratio of 5:2.

Thus, a simple, two-tiered, linear weighting system was used that partitioned the measures into traffic and environmental sets, both of which had their own measure-specific weights as produced in the Delphi process.

Figure 1. Example of Delphi measure weighting response form.

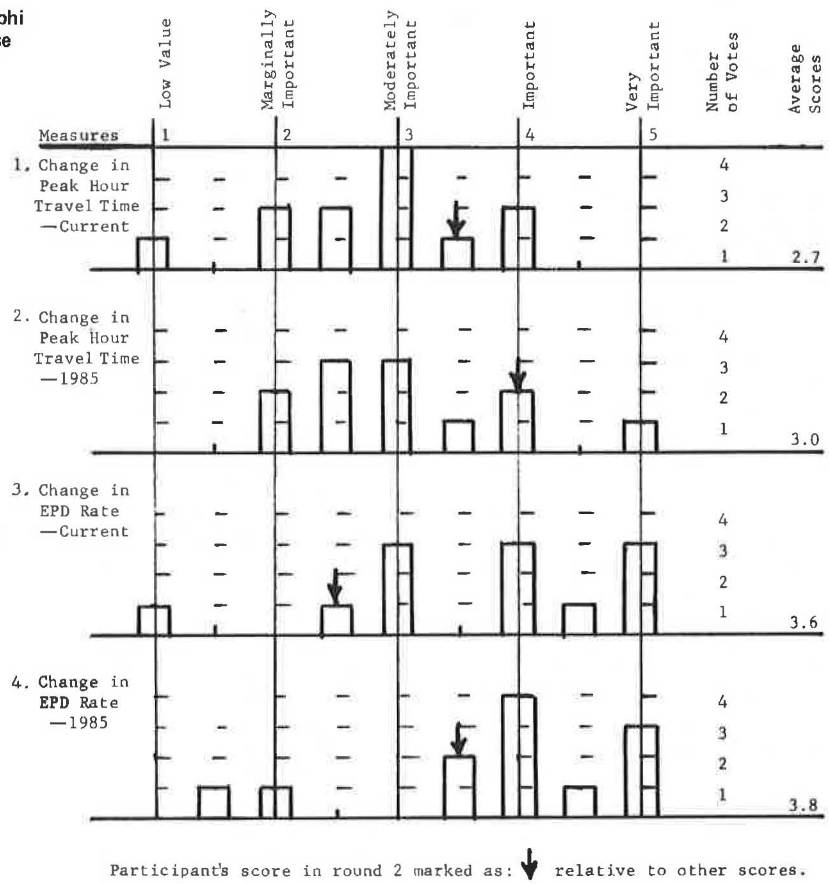


Table 1. Means and variances of measure weights for three rounds of Delphi process.

Measure	Round 1 Average	Round 1 Variance	Round 2 Average	Round 2 Variance	Round 3 Average	Round 3 Variance
Peak-hour travel time						
1975	2.7	0.84	2.7	0.75	2.9	0.27
1985	3.0	0.61	3.0	0.81	2.9	0.97
Equivalent property damage rate						
1975	3.7	1.79	3.6	1.47	3.8	0.79
1985	4.2	0.78	3.8	1.24	4.1	1.3
Volume/capacity						
1975	3.5	0.91	3.5	1.2	3.7	0.46
1985	3.9	0.04	3.8	0.95	3.9	0.32
Off-peak daily travel time						
1975	2.5	1.0	2.6	0.65	2.6	0.28
1985	3.2	1.31	2.8	1.19	2.8	0.62
Environment, 1975						
Noise pollution	2.7	0.39	2.7	0.61	2.6	0.45
Air pollution	2.5	0.79	2.5	0.94	2.5	0.8
Dwellings	3.4	2.17	2.8	1.86	3.1	0.95

Note: 1985 environmental variables have the same value as 1975 variables.

Table 2. Evaluation matrix.

Project	Effectiveness of Performance Measures								Effectiveness of Environmental Measures			
	1975 Changes[a]				1985 Changes[a]				1975 Changes[b]		1985 Changes[b]	
	Peak Travel Time (s)	EPD Rate	Volume/ Capacity Ratio	Avg Daily Travel Time (s)	Peak Travel Time (s)	EPD Rate	Volume/ Capacity Ratio	Avg Daily Travel Time (s)	Noise	Air	Noise	Air
1	-6	1.45	0.17	-3	-8	1.45	0.17	-3	0.5	0.5	0.5	0.5
2	-11	0.28	0.06	-4	-10	0.28	0.06	-3	0.5	0.5	0.5	1.0
3	228	4	0.12	228	228	4	0.24	228	0.5	0.5	0.5	0.5
4	21	2	-0.05	16	21	2	0.08	16	0.5	0.5	0.5	0.5
5	0	2.4	0.2	12	108	2.4	0.22	42	0.5	0.5	0.5	0.5
6	18	3.5	0.06	18	18	3.5	0.05	18	0.5	0.5	0.5	0.5
7	0	3.9	0.13	-2	11	3.9	0.17	12	0.5	0.5	0.5	0.5
8	192	0	0	193	192	0	0.01	193	0.5	0.5	0.5	0.5
9	17	5.1	0.24	15	70	5.1	0.28	10	0.5	1.0	0.5	1.0
10	0	2.7	0.15	0	0	2.7	0.34	0	0.5	0.5	0.5	0.5
11	12	7	0.18	0	348	7	0.22	0	0.5	0.5	0.5	1.0
12	5	0.38	0.22	0	45	0.38	0.28	0	0.5	0.5	0.5	0.5

[a] Negative changes are reductions in performance caused by the project.
[b] No project required taking dwelling units, and thus this measure was deleted; other environmental measures were scaled as described in the text.

TECHNICAL ANALYSIS

The highway projects analyzed in this effort included those that dealt with intersections and those concerned with roadway sections: widenings, new signals, additional lanes, bridge replacement, and new portions of roadways. Standard forecasting tools were used to predict changes in traffic volumes, travel speeds, travel time, delays, accidents, and air quality for each of the proposed projects, both now and in 1985. Methods included studies of intersection delay and accident reduction, limited use of traffic assignment for analyzing larger projects, and simplified air-quality and noise-level forecasting tools.

Measures for the no-build alternatives were collected from several sources. On-site field observations were carried out to obtain operating speeds and delay times for peak and off-peak periods. Data collected in this way also permitted a more accurate calibration of the forecasting tools. Volume data were obtained from inventory files and from supporting documentation for each of the proposed projects. Forecast (1985) no-build volumes were synthesized from past, 1980, and 1990 assignments over the existing highway network.

In most cases, the nature of the projects allowed two simplifying assumptions to be made: the independence of the project and negligible traffic diversion caused by a project. Since the projects were local, relatively small in scale, and scattered throughout DuPage County, the first assumption—that of minimal project interaction—was reasonable. Before-and-after data on similar, previously implemented projects in DuPage County showed no clear pattern of traffic diversion. In all cases, natural growth could have accounted for any changes in volume that were observed. Most projects were therefore treated as though no traffic diversions would result. In a few proposals, the nature of the project suggested that diversions would occur; these were subjected to a more detailed analysis, which included a simplified traffic assignment.

COST-EFFECTIVENESS ANALYSIS

Effectiveness measures for each of the projects for both 1975 and 1985 were assembled in an evaluation matrix in which the rows were projects and the columns were dimensions of effectiveness. Table 2 gives a simplified version of the actual matrix presented to decision makers, showing the trade-offs between projects for a single measure (cells in a single column) as well as the performance profile of each project across the measures (cells in a single row). This structured data set was presented to decision makers and remained available to them throughout the evaluation process. Their expressed preference, however, was to seek a collapsing of the data to fewer dimensions to facilitate understanding and choice.

It seemed apparent that two interrelated factors increased the willingness of decision makers to compromise the quantitative evaluation procedure in favor of simplicity. First, it became increasingly clear throughout the technical process that the TSC members reserved the right to make the final choice of a TIP independent of the results of the quantitative studies. If the studies proved instructive, they intended to use them; still, the intricacies of intercommunity negotiations were not to be given up for any formal evaluation tool, and thus the use of a simpler tool made sense. In addition, because of the relatively small scale of the entire set of projects and the established working relation among the decision makers, it was expected that considerable richness of information exchange would exist when any quantitative structure was used.

The second factor of importance is that this effort represented the first experience most of the decision makers had had with a formal approach to transportation evaluation. This led to a preference to start slowly and carefully (from their perspective) and not to be swallowed up by technical detail. There may be logic in the decision on the part of the technical analyst to work with simplified tools at the start in order to get a foot in the door.

The traffic-related effectiveness measures were originally prepared on a per user (i.e., per vehicle) basis to account for the fact that some measures were daily and others were annual. Information in the evaluation matrix was then factored by the appropriate daily volume for each project to produce measures of effectiveness per day.

Because measures of effectiveness were in different units, there was the possibility that "large-unit" measures such as daily travel-time savings might dominate "small-unit" measures such as dwellings taken. But it was important to ensure that the priorities assigned to various measures were those selected by the decision-makers (through the Delphi process described above) and not some technical feature of the measures. Therefore, all measures were converted from an absolute to a relative basis by dividing each element in a given column by the largest element in that column. This scaling approach is arbitrary, and a number of other options might have been used. The method selected set 1.0 as the maximum value and related all other values to that level; no measure could be less than zero.

The environmental measures were treated separately from the performance measures. Air pollution and noise levels were predicted for each project, related subjectively to established standards, and scored directly on a 0 to 1.0 scale by using the following decision rule: significant environmental deterioration with the project—0; no change or slight improvement in environmental conditions—0.5; improvement in conditions (including cases where the project is necessary to meet standards)—1.0. A similar arbitrary scaling system was used for dwelling units taken: no dwelling units taken—1.0; one to five units taken—0.5; more than five units taken—0.

The arbitrary nature of the resulting scale cannot be overlooked. It implies that the highest observed measure is the best possible, which is not the case. It arrays alternatives on a short scale between 0 and 1.0 with a bias toward 1.0 Most significantly, this method for rescaling incommensurables to a common arbitrary dimension assumes the feature of linearity in unit conversion, which is not realistic. For example, it assumes that the common-dimension value of the gap between 2000 and 4000 in one measure is the same as that between 2 and 4 on another measure. Although the approach chosen was simpler, there are conceptual advantages associated with using more complicated scaling methods that allow for the possibility of nonlinearities in this transformation process (7).

These scaled effectiveness measures were then aggregated by using the Delphi weights. The result was a scalar effectiveness score for each project. These were reported to the decision makers separately and in the form of cost-effectiveness indexes by dividing the effectiveness of each project by its capital costs. Operating and maintenance costs were not treated because it appeared that the proposed projects would not impose much change in existing operating and maintenance costs.

PROJECT READINESS

Because funds in the FAUS program are allocated on a yearly basis and in general cannot be carried over to subsequent years, it is important to the subregional evaluation and the decision-making process to ensure that selected projects can start in the year for which they are programmed. Thus, it is important to know when a project will be ready for implementation as well as to know its cost-effectiveness.

Therefore, a checklist of administrative steps necessary to implement federally funded projects was prepared. The list included the following items:

1. Passage of TSC resolution;
2. Decision on sources of local match;
3. Development and approval of environmental impact statement (EIS), if required;
4. Public hearings (dependent on outcome of item 3 above);
5. A95 and state review processes;
6. Approval of design report (a description of the extent and nature of the project, which may include an EIS);
7. Completion of a joint funding agreement (final funding commitment of local, state, and federal governments);
8. Right-of-way acquisition, if necessary;
9. Preparation of the construction plan; and
10. Target letting date.

By knowing the type of project and the implementation time historically required for similar projects, it was possible to estimate the expected time it would take a project to proceed through all required stages. Projects not likely to be ready for implementation in the programming year were tabled for later consideration.

DEVELOPMENT OF PRIORITIES

The cost-effectiveness index was used to prioritize the remaining projects subject to the constraint of the available budget. That is, projects were listed by decreasing cost-effectiveness until the budget was consumed. Some shifting of marginal projects is usually necessary to fit proposed projects into the available budget.

If maximization of benefits were the objective, it would be correct to use incremental benefit-cost analysis, or net present worth analysis, and in more complex cases to apply mathematical programming tools (8) to this ranking task. Here, however, the concern was not to maximize countywide benefits but to ensure a fair share of funds for participating communities where that share supported good projects. In this case, cost-effectiveness is more credible as a ranking tool. In addition, local decision makers desired considerable flexibility of choice so that their actions could reflect the needs and desires of communities and interest groups. Such factors cannot be easily accommodated within a formal evaluation framework. Indeed, decision makers have the responsibility for bringing such factors into the choice process; thus, it is logical to leave them with enough slack in the list of recommended priorities so that they can satisfy the variety of needs they represent.

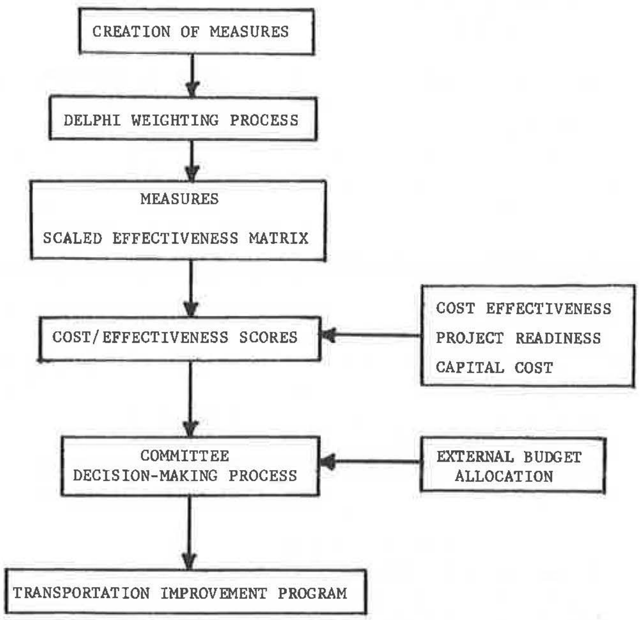
The tables below give a list of projects as they might be selected to be included in the annual element of the TIP—based on an attempt to maximize cost-effectiveness subject to the constraint on the budget—and the list of priority projects selected by local decision makers:

Project	Cost-Effectiveness	Cost ($000 000)
A	62.6	0.385
B	28.6	0.300
C	16.1	0.912
D	14.2	0.610
E	7.9	0.600
F	7.4	3.3
H	5.7	0.172
I	3.7	0.601
Total		6.88

Project	Cost-Effectiveness	Cost ($000 000)
A	62.6	0.385
C	16.1	0.912
F	7.4	3.3
G	6.0	1.065
I	3.7	0.601
J	2.9	0.570
Total		6.833

The correlation between the lists in these tables is apparent. Of the six projects selected by decision makers, all but one were selected by the cost-effectiveness method. Of the eight projects selected by the method, four were chosen by decision makers. The differences between these lists were easily explainable in terms of local history, needs, and compromises that

Figure 2. Overall evaluation and decision-making process.



are a natural part of the cost of a multiplicity of jurisdictions working together in planning and programming.

Although it can be argued that the differences between the recommended and adopted priority lists were substantial, given that this was the decision makers' first experience with using organized quantitative techniques for programming, it is not an unreasonable outcome. Even though the decision makers themselves called for the use of a more structured approach, they were not fully prepared to yield their negotiating positions totally to the results of the analysis. This is particularly the case because the analysis was performed by the MPO, which was to a certain extent viewed as an outside agency invited to assist in the programming process but not to seize it. Based on the reactions of decision makers, it is expected that their willingness to make better use of formal analysis has increased and, with proper technical support, will continue to expand in the coming years. But the forum for cooperative decision making had, in this case, begun to function.

SUMMARY

The evaluation and decision process developed and tested in this effort is shown in Figure 2. It is nothing more than a simple linear weighting scheme, but its development in close working relationship with local decision makers makes it uniquely appropriate for supporting local transportation investment decisions. Decision makers initially sought out the assistance of such a scheme; they participated actively in the selection of the measures of effectiveness; and they worked together in a Delphi process to establish the weights associated with each of the measures. With the assistance of the technical staff, they studied the raw measures of effectiveness, and they carefully reviewed the products of the formal evaluation process. Although the process itself gave them a set of project rankings, they elected to implement a modified but quite similar ranking list in an effort to accommodate local goals.

The closeness of the decision makers' preferred project ranking to the product of the evaluation scheme suggests the merit of the general strategy if not of the evaluation scheme itself, not only in helping to justify a particular set of choices in this case but also as a potential tool for simplifying the choice process in future years. The differences between the rankings of the decision makers and those produced by the evaluation technique underscore the notion that the political process is still in control of investment decisions in the public sector and thus is still in a position to respond to the unique characteristics of the needs of individuals and groups.

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