PRIORITY ANALYSIS PROCEDURE FOR RANKING HIGHWAY IMPROVEMENT PROJECTS

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This paper presents a priority analysis scheme for ranking highway improvement projects. The procedure is based on a scoring model approach that evaluates highway projects in terms of as many as 26 parameters that are divided into eight groups: need, deficiency, continuity, benefit-cost, local opinion, and economic, social, and environmental consequences. For each project, the individual parameters are evaluated and combined through a set of weighting factors into one or two indexes that can then be used to rank the projects. The selection of parameters and a set of weighting factors was determined from responses to questionnaires distributed to state transportation board members, department of transportation officials, and regional and local planners within the state of Georgia. The improvement projects are categorized according to 10 functional classes and nine improvement types. The projects are ranked within each category.

•MORE THAN $200 million was spent by the Georgia Department of Transportation (GDOT) in fiscal year 1972 for highway improvements. This amount, though large, cannot begin to fill the $10 billion worth of highway needs estimated for the years 1970 through 1990. To accommodate this scarcity of financial resources, means must be developed by which highway improvements can compete objectively for limited capital resources. Fundamental to every known capital allocation scheme is a procedure for ranking the criticality of highway improvement projects to maximize the use of available resources.

Currently in Georgia, as in many other states, priorities are assigned to improvement projects largely on the basis of subjective judgments developed from past experience. Priorities that are established subjectively run the risk of personal engineering bias, lack of comprehensiveness, and political bias. Furthermore, the increasing number, magnitude, and complexity of the programs will soon make subjective priority analysis unmanageable.

The priority scheme reported here was developed to satisfy GDOT's desire for a priority analysis procedure that recognizes needs and deficiencies and that also incorporates the following features: socioeconomic consequences, environmental consequences, continuity considerations, and state and local political reactions.

The new procedure should also be capable of rapid execution and be suitable for implementation in the immediate future without extensive changes in the existing data collection systems or in the existing planning process. Three general guidelines were established for evaluating a priority analysis procedure (6):

1. Objectivity—subjective judgments and opinions should be minimized so that answers can be defended;
2. Comprehensiveness—the procedure should be devised to permit the consideration of all projects; and

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Publication of this paper sponsored by Committee on Transportation Planning, Programming, and Evaluation.

3. Consistency—projects selected should be consistent between themselves and from year to year.

Most of the existing procedures meet these guidelines to some degree. However, the priority procedure presented has important elements that are not included in existing guidelines.

Social, economic, and environmental aspects of highway improvement projects have generally been omitted from priority analysis procedures, possibly because these aspects are intangible and require subjective judgments—a violation of the basic guideline of objectivity. However, recent emphasis on the social, economic, and environmental aspects of highway improvements dictates that, for certain types of highway improvements, they deserve equal, if not more than equal, consideration with the traditional need, deficiency, and service factors. A highway official (2) commented at a recent conference:

> The socioeconomic aspects of highway projects are becoming more and more important in priority programming. Some people believe that highways should be used primarily as an economic development tool to revitalize depressed areas, such as Appalachia, by providing access and mobility to and within these areas. Others are of the opinion that urban highways should only be developed when they are designed to achieve broader urban goals, such as better housing, more beautiful communities, or better recreational and social opportunities. Highways do contribute in greater or lesser degree to such objectives, and so decision makers are giving increased attention to such views, along with needs of the people for efficient motor vehicle transportation.

Federal legislation and guidelines, such as the National Environmental Policy Act and Federal-Aid Highway Acts of 1970 and 1972, require state highway or transportation agencies to prepare careful and thorough investigations of social, economic, and environmental consequences of federal-aid highway projects. These requirements have caused a substantial change in the planning process. The role of community participation in the planning process has also gained considerable momentum of late. It is, therefore, important to include such factors in the priority analysis process.

EXISTING PRIORITY ANALYSIS PROCEDURES

Priority analysis is the systematic process of ranking improvement projects according to certain criteria that measure their relative degree of need, urgency, or desirability. Over the years, many procedures have been developed for priority analysis (4, 5, 7-14, 22). Most of these are based on some form of sufficiency or deficiency rating. Conceptually, these procedures all consist of

1. A rating scheme to establish the relative degree of need, deficiency, or desirability of the projects by using quantitative and qualitative parameters that describe each project and
2. A ranking scheme to order projects in accordance with ratings and other qualitative inputs.

Although existing priority analysis procedures vary widely in detail, they can be divided into two broad groups: sufficiency ratings and economic analysis. Sufficiency ratings are composite ratings, in which a single composite score is calculated for each project and the projects are then ranked according to their scores [the procedure used by the Arizona Highway Department is a forerunner in this category (7)], or priority arraying, in which the projects are segregated into priority arrays or groups based on ratings of individual factors [Tennessee and Washington use procedures of this form (9, 10)]. In economic analyses, the projects are ranked according to their economic importance, expressed mostly in terms of benefit-cost ratio or rate of return. The Pennsylvania procedure is a prime example of this approach (11).

Without substantial changes, neither sufficiency ratings nor economic analyses are an adequate approach to priority rating. Sufficiency ratings measure the urgency for improvement, and economic analysis measures the benefit or importance of the improvement. Unfortunately, a project with a high degree of criticality may not have high economic importance, and a project with a high indicated economic return may not represent a critical need. The economic analysis approach also has drawbacks in estimating and quantifying benefits, which have prevented its widespread use. In the sufficiency rating approach and, to a lesser extent, the economic analysis approach, the rating is based on the need or deficiency of the road sections themselves, but it is the improvement projects that are assigned priorities.

Both of the approaches to sufficiency rating, composite score and priority arraying, are also open to criticism. Consider, for example, a project with a high score in only one element such as a road section with a critical structural deficiency and no functional or safety deficiencies, and another project with a low to moderate score in each of the three elements. A composite score cannot distinguish between the two projects. On the other hand, the priority arraying approach places all the weight on only one of the elements and fails to examine the overall situation.

An optimization approach has recently been proposed that is conceptually quite different from the existing procedures (14). The optimization approach combines the functions of priority analysis, program formulation, and project scheduling into one operation that produces the optimum schedule of available projects through the use of precise analytical techniques such as linear, quadratic, and dynamic mathematical programming. Linear programming is by far the most popular and most appropriate of these techniques. The optimization approach has many attractive prospects, but the difficulties encountered in the estimation and quantification of benefits and consequences cast some doubt on its practicality at this time. However, with technological advances in these areas, optimization may be the procedure of the future.

CONCEPTUAL FRAMEWORK OF THE PROPOSED PROCEDURE

A scoring model approach was chosen for the proposed procedure. This procedure can be implemented within the present state of technology. It also overcomes some of the shortcomings of the sufficiency rating and economic analysis approaches. The scoring model concept can be expressed mathematically as

$$S_j = \sum_{i=1}^{P} W_i R_{ij} \qquad (1)$$

where

S_j = overall score or rating of project j,
W_i = weighting factor (relative importance) of the ith parameter,
P = number of evaluating parameters, and
R_{ij} = individual score or rating of the ith parameter of project j.

Equation 1 provides a basis for ranking projects with a similar or identical set of evaluating parameters and weighting factors. However, because of the wide diversity in highway functional classes and types of improvements, unlike projects must be divided into separate categories. A two-dimensional categorization was chosen that identifies each project by both a functional class and an improvement type. The functional class describes the level and use of the highway with which the project is associated, and the improvement type describes the nature of work to be done.

The scoring model is applied to priority analysis as follows.

1. Highway improvement projects are categorized according to their functional classification and improvement types so that they may be evaluated and compared under compatible sets of parameters and consequences.
2. The evaluating parameters and consequences that are pertinent to each category under consideration are identified.
3. The relative importance of the various evaluating parameters is determined through a set of weighting factors.
4. For each project in each category, the rating of each evaluating parameter is developed through objective, analytical methods where possible; otherwise, subjective judgments are made.
5. The overall rating of each project is developed by combining the individual parameter ratings into one or two indexes through the use of relative weighting factors.

The priorities of projects in each category can then be determined based on their overall index or indexes.

Categorization of Improvements

Improvements under different functional classifications and types of work should be evaluated under different but compatible sets of criteria. The first step of the priority analysis procedure is, therefore, to segregate the improvement projects into categories based on their functional classification and type. Categorization of improvement offers other significant advantages in addition to compatibility. Categorization provides a basis for legislative and administrative directives in terms of resource allocation, fund appropriation, policy making, and system priorities.

Ten functional classes of highways and streets were selected for use in the priority analysis procedure:

1. Urban Interstate,
2. Rural Interstate,
3. Urban principal arterial,
4. Rural principal arterial,
5. Urban minor arterial,
6. Rural minor arterial,
7. Urban collector,
8. Rural collector,
9. Urban local, and
10. Rural local.

The segregation of projects by improvement type is much less well-defined than functional classification. Nine types of improvements were adopted after careful studies of the nature of work involved, the funding sources, and the distribution of projects under the various improvement types. Table 1 gives the nine types of improvements and brief descriptions of each.

Identification of Evaluating Parameters

A set of evaluating parameters was developed to measure the significant impacts of all categories of highway projects. Parameters were identified from existing priority analysis and evaluation procedures (3-14, 17-21), and, where necessary, additions were made to provide adequate coverage of all significant impacts. The list of candidate parameters was reduced by analyzing the units of measure needed to evaluate the different parameters and the sources of data that can support the measures.

After careful study and review, 26 parameters were identified for which data are readily available. The parameters are grouped under eight broad headings:

Need factors

1. Need as identified by state, regional, or local transportation plans;
2. Need as identified by state, regional, or local officials;
3. Need as recommended by U.S. DOT officials evaluating the project;

Deficiency factors

4. Existing and projected traffic volume;
5. Existing traffic volume-capacity ratio;
6. Existing condition of highway facilities including pavement and structure;
7. Accident experience;
8. Deficiencies in roadway geometrics and alignment including roadway width, stopping and passing sight distances, horizontal and vertical curves, and horizontal and vertical clearance of bridge structures;

Continuity factors

9. Continuity with existing facilities;
10. Continuity and coordination with other improvements,

Highway-user-related factor

11. Benefit-cost ratio including the benefits of travel cost and time and accident potential and the costs of construction, operation, and maintenance;

Human factors

12. Local opinions from publications and hearings as well as requests (or complaints) from local civic groups and individuals;

Economic consequences

13. Desirability with respect to state, regional, and local community goals and long-range, land use, and economic development plans;
14. Effect on land value and development;
15. Effect on agricultural activities;
16. Effect on commercial and industrial activities;
17. Effect on local construction industry and employment;
18. Relocation of public utilities;

Social consequences

19. Disruption to community during construction;
20. Relocation of residential and commercial units;
21. Effect on neighborhood life and social patterns;
22. Preservation of historical, religious, and institutional areas;

Environmental consequences

23. Aesthetics and visual effects;
24. Air and noise pollution and vibration;
25. Water pollution and effect on drainage; and
26. Conservation of natural resources.

Not all parameters apply to every type of improvement. For example, relocation of public utilities is rarely of significance in a minor highway upgrading. Thus, we view the 26 parameters as the universe, and for each improvement type we select a subset of parameters that are significantly affected by the improvement type. It is assumed that all functional classes share the same set of evaluating parameters for a given type of improvement.

Units of measure and criteria values were established for each of the 26 parameters for each of the functional classes. The definition of units of measure and criteria values for tangible parameters poses little problem. However, for intangible parameters, their definition is of much concern and has to be established subjectively.

PREPARATION AND ANALYSIS OF QUESTIONNAIRES

To identify the pertinent parameters for each type of improvement and, at the same time, to establish the relative importance of the parameters in terms of weighting factors, a set of questionnaires was developed with the following objectives:

1. To serve as an identification process to select the pertinent parameters from the

Table 1. Improvement types.

Improvement Type	Description
1. New highway construction	New highway construction and related engineering work
2. Reconstruction and major highway upgrading	Reconstruction, relocation, realignment, addition of lanes, and widening
3. Minor highway upgrading	Resurfacing, repaving, grading, drainage, paving shoulders, and surface treatment
4. New and replacement structures	Bridge structures, culverts, sign support structures, and special structures
5. Safety improvements	Safety projects, pedestrian overpasses, guardrails, medians, separator and sidewalk construction
6. Traffic engineering improvements	TOPICS, intersection improvements, traffic signals, flash and overhead signing, and street lighting
7. Beautification projects	Landscaping and acquisition of scenic rights-of-way
8. Railroad crossing projects	Railroad overpasses, signals, and crossing markings
9. Special projects	Projects that cannot be classified into any of the above improvement types, such as rest areas, weighing stations

Figure 1. Sample questionnaire rating form.

	FACTOR	IMPORTANCE SCALE (No Importance … Extreme Importance)
NEED FACTORS	Need as identified by state, regional or local transportation plans	0 1 2 3 4 5 6 7 8 9 10
	Need as identified by state, regional or local officials.	0 1 2 3 4 5 6 7 8 9 10
	Need as recommended by DOT officials evaluating the project.	0 1 2 3 4 5 6 7 8 9 10
DEFICIENCY FACTORS	Existing and projected traffic volume.	0 1 2 3 4 5 6 7 8 9 10
	Existing traffic volume/capacity ratio	0 1 2 3 4 5 6 7 8 9 10
	Existing condition of highway facilities	0 1 2 3 4 5 6 7 8 9 10
	Accident experience (including hazard index)	0 1 2 3 4 5 6 7 8 9 10
	Existing deficiencies in roadway geometrics and alignments	0 1 2 3 4 5 6 7 8 9 10
CONTINUITY FACTORS	Continuity with existing facilities.	0 1 2 3 4 5 6 7 8 9 10
	Continuity and coordination with other improvements.	0 1 2 3 4 5 6 7 8 9 10
HIGHWAY-USER RELATED FACTOR	Benefit-cost ratio	0 1 2 3 4 5 6 7 8 9 10
HUMAN FACTOR	Local opinions from publications and hearings as well as requests (or complaints) from local civic groups and individuals.	0 1 2 3 4 5 6 7 8 9 10
ECONOMIC FACTORS	Desirability with respect to state, regional and local community goals and long-range, land-use, and economic development plans.	0 1 2 3 4 5 6 7 8 9 10
	Consequences on land value and development	0 1 2 3 4 5 6 7 8 9 10
	Consequences on agricultural activities.	0 1 2 3 4 5 6 7 8 9 10
	Consequences on commercial and industrial activities .	0 1 2 3 4 5 6 7 8 9 10
	Consequences on local construction industry and employment	0 1 2 3 4 5 6 7 8 9 10
	Dislocation and/or relocation of public utilities. .	0 1 2 3 4 5 6 7 8 9 10
SOCIAL FACTORS	Disruption to community during construction.	0 1 2 3 4 5 6 7 8 9 10
	Dislocation and/or relocation of residential and commercial units	0 1 2 3 4 5 6 7 8 9 10
	Consequences on neighborhood life and social patterns.	0 1 2 3 4 5 6 7 8 9 10
	Preservation of historical, religious, and institutional areas	0 1 2 3 4 5 6 7 8 9 10
ENVIRONMENTAL FACTORS	Aesthetics and visual effects.	0 1 2 3 4 5 6 7 8 9 10
	Air pollution, noise pollution and vibration	0 1 2 3 4 5 6 7 8 9 10
	Water pollution and effect on drainage	0 1 2 3 4 5 6 7 8 9 10
	Conservation of natural resources.	0 1 2 3 4 5 6 7 8 9 10
		No Importance … Extreme Importance

26 for each type of improvement and

2. To provide a basis for determining an initial set of weighting factors.

The questionnaires ask members of the rating panel to evaluate the importance of the 26 parameters for each of the nine types of improvements on a scale of 0 to 10. Zero denotes no importance or inappropriateness; 10 signifies extreme importance. A sample rating form is shown in Figure 1.

The rating panel was comprised of three groups of people, each with a direct concern over the selection of highway improvement projects in Georgia:

1. Georgia Transportation Board members, each of whom represents one of the 10 congressional districts in the state (the board members may be considered as the top-level decision makers because they give the final approval for each project);
2. Responsible Georgia Department of Transportation officials; and
3. Area planning and development commissions and urban area planning commissions.

The responses of the three groups were analyzed separately to determine whether the judgments of the groups differed significantly. Weighting factors were based on the overall judgment of the panel. When significant differences occurred between groups, weighting factors were sometimes adjusted on the basis of a logical rationale.

Overall, 57 of the 72 distributed questionnaires (about 80 percent) were returned with good balance for each group. For each parameter, the responses were tabulated, and the means and standard deviations of the importance ratings were computed for each group as well as for the three groups together. The differences among the means of the three groups were tested for statistical significance by using an F-test with one-way analysis of variance. These tabulations and calculations were repeated for each of the 26 parameters for each of the nine improvement types. The correlations and interrelationships between the parameters for each type of improvement were also evaluated by using correlation and factor analyses.

A parameter was deemed inappropriate for a given type of improvement if

1. Its mean importance rating was very low,
2. A significant fraction of raters considered it inappropriate, or
3. A relatively low mean importance rating was combined with a high standard deviation, which indicated widespread disagreement on the importance and appropriateness of the parameter.

Candidate parameters for exclusion were reviewed after data availability, cost of obtaining data, and pertinency of the parameters were considered subjectively.

The relative importance of pertinent parameters is expressed in terms of weighting factors that were based on the mean importance ratings. The initial set of weighting factors for each of the first eight types of improvements is given in Table 2. (The last type of improvement, special projects, was not included in the analysis because of the wide variation among projects.) Parameters deleted from the master list have zero weighting factors and are noted as not applicable.

FORMULATION OF PRIORITY ANALYSIS PROCEDURE

Two alternative approaches to the priority analysis procedure are shown in Figure 2. A proposed project is first assigned a category on the basis of its functional classification and improvement type. The set of pertinent parameters and their appropriate weighting factors are selected for the improvement type. Each pertinent parameter is then evaluated by using established units of measure and criteria values on a scale of 0 to 10.

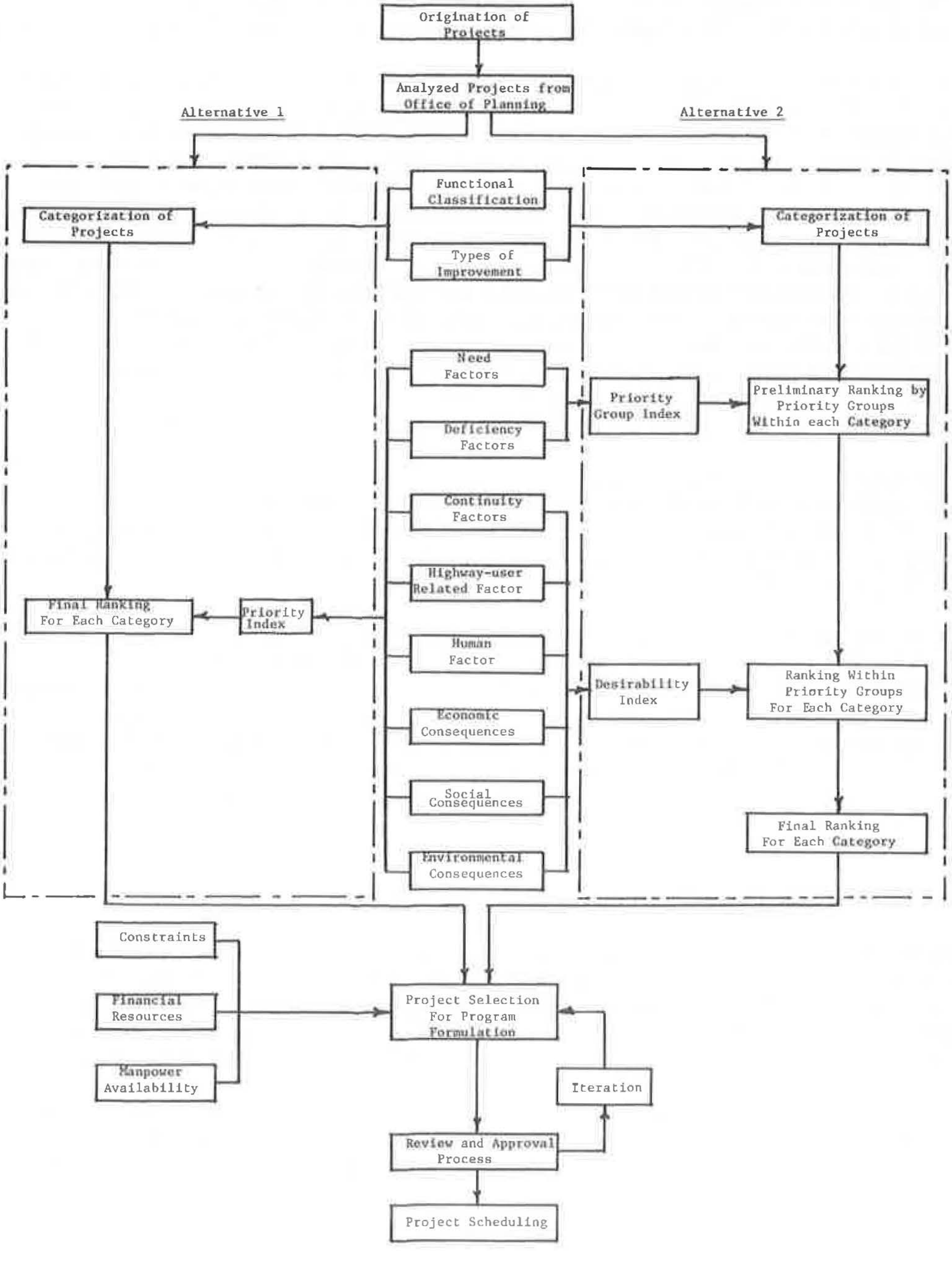
The individual ratings of the pertinent parameters are collapsed into one or two dimensions to provide a basis for ranking the projects. There are two approaches to this collapsing process. The first is to combine all parameter ratings into a single

Table 2. Initial set of weighting factors.

Parameter	Improvement Type 1	2	3	4	5	6	7	8	Parameter	Improvement Type 1	2	3	4	5	6	7	8
1	8.8	8.4	6.1*	5.4*	5.7*	7.2	5.1*	7.2*	14	6.1	5.7	4.2	NA	NA	NA	NA	NA
2	7.2	7.2	7.0	7.1	7.1	8.1	7.0	7.8	15	5.3	4.3	NA	NA	NA	NA	NA	NA
3	8.1	7.8	8.6*	9.0*	8.2	8.6*	7.0*	8.2	16	6.3	5.8	4.4	4.8	NA	4.2	NA	NA
4	8.1	8.1	6.7	6.6*	7.5	7.8	5.3*	8.3	17	4.2	3.8	NA	NA	NA	NA	NA	NA
5	8.2	8.3	6.5	7.9*	7.3	8.4	NA	6.6*	18	3.6*	4.3	NA	NA	NA	NA	NA	NA
6	7.1	7.5	8.7	8.7	8.3	8.1	NA	7.5	19	5.0	5.1	4.9*	4.8	NA	NA	NA	4.1*
7	7.5*	8.3	7.9	8.7	9.6	9.3	NA	9.7	20	6.6	6.2	NA	NA	NA	NA	NA	NA
8	6.9	7.8	5.7*	7.3	8.0	8.2	NA	8.3	21	7.5	6.2	NA	NA	NA	NA	NA	NA
9	7.6	6.9	4.7*	5.8	5.2*	6.8	NA	6.1*	22	6.8	6.8	NA	NA	NA	NA	7.0*	NA
10	7.9	7.7	6.0	6.4	5.8	6.8	4.8*	6.4	23	6.8	6.0	4.7	6.2	4.8	5.7*	9.2	4.5*
11	6.5	6.2	4.4*	4.2*	NA	4.3*	NA	4.6*	24	6.8	6.5	NA	NA	NA	NA	5.4*	NA
12	6.3	5.9	5.1	4.5	5.9	5.7	6.6*	6.8	25	7.8	6.6*	6.5*	7.0	NA	NA	6.2*	NA
13	8.9	7.6*	4.9*	6.2*	4.5*	NA	6.3*	5.7*	26	7.7	6.7*	5.0*	5.8*	NA	NA	6.9*	NA

Note: Asterisk indicates ajdustment in weighting factors because of significant differences between rating groups.

Figure 2. Proposed priority analysis procedure.



composite score or priority index. The second approach is to divide the parameters into two groups and to treat the groups independently.

First Alternative

In the first approach, the ratings for all pertinent parameters are collapsed into a single composite score, the priority index, which can be expressed mathematically as

$$P_j = \sum_{i \in M} A_i R_{ij}^{N_j} \tag{2}$$

where

P_j = priority index for project j,
$i \in M$ = parameter i within the set M of pertinent parameters that have weighting factors greater than zero, excluding those with no available information,
A_i = normalized weighting factor for parameter i,
R_{ij} = rating of parameter i for project j, and
N_j = normalizing index for project j.

Equation 2 is essentially an extension of the basic scoring model concept. There are, however, three major modifications. The first modification is that a pertinent parameter with no available information for its evaluation is treated as if it is inappropriate, that is, as if the parameter has a zero weighting factor. This provides more flexibility in the model so that projects with only fragmented and incomplete information can be evaluated. The symbol $i \in M$ thus denotes those parameters within the set M of parameters with both the weighting factors greater than zero and information available for their evaluation.

The second modification follows from the first one. Inasmuch as some of the pertinent parameters with weighting factors greater than zero may not be applicable because of a lack of information, the number of evaluating parameters may not be the same for all projects within the same category. This variation in number of evaluating parameters poses a serious problem because the projects within the same category are no longer evaluated on the same scale or dimensions. The weighting factors must therefore be converted to the same scale or dimension to accommodate this variation.

The simplest approach to this problem is to normalize the weighting factors to a (0, 1) scale. This is accomplished by dividing each weighting factor by the sum of all weighting factors within the set M of pertinent parameters, which can be expressed mathematically as

$$A_i = W_i \Big/ \sum_{i \in M} W_i s \tag{3}$$

where

A_i = normalized weighting factor for parameter i,
W_i = weighting factor for parameter i, and
s = a constant [multiplying by s converts W_i from a (0, 1) scale to a (0, s) scale; the value of s may be chosen as desired].

The third major modification is the use of a normalizing index as an exponent to the individual parameter ratings. (The normalizing index may alternatively be used as a multiplying factor to the individual parameter ratings.) The normalizing index is defined as

$$\text{Normalizing index} = 1 + \log\left(\frac{\text{projected traffic volume} \times p}{\text{estimated project cost}}\right)^q$$

where

log = logarithm to the base 10 and
p, q = constants.

The normalizing index is designed to incorporate the cost element into the evaluation process. This index may be viewed as an indicator of the importance of the number of users per unit of cost. This procedure favors improvements on highway facilities with high traffic volume and low capital cost. The constants p and q allow the index to be calibrated and adjusted. The use of the logarithm to the volume-cost ratio moderates the effects of extremely large or small ratios.

The ranking of projects in each category in the approach is based on the priority indexes of the projects. The project with the highest priority index is ranked first, the project with the next highest priority index is ranked second, and so on.

Second Alternative Approach

In the second approach, two indexes, a priority group index and a desirability index, are used to rank projects. The priority group index is determined by combining the parameter ratings on the need and deficiency parameters only. The remaining parameters of continuity, benefit-cost ratio, local opinions, and socioeconomic and environmental consequences are collapsed into the desirability index. The basic assertion for this two-index approach is that the 26 parameters can be separated into two groups: (a) the need and deficiency parameters, which evaluate the criticality or urgency of a project, and (b) the remaining parameters, which identify the importance of a project to a variety of interest groups.

The key to combining the two indexes is the relative significance, for priority determination, of the project urgency and project importance. For the purposes of this paper, urgency is placed ahead of importance for the following reason: Highways are at present the predominant mode of transportation and will likely remain so until satisfactory alternative modes are developed. To provide a sufficient level of mobility, service, and safety to the public, the existing highway network must be maintained to an acceptable quality standard. One of the main objectives of highway improvements is, therefore, to improve the highway network to a satisfactory level and to maintain it. A project that is in critical need should be implemented as soon as possible and thus should be given a high priority. For example, a bridge structure that is failing should be replaced or repaired as soon as possible, although it may have relatively little importance in terms of the second group of parameters.

Existing data collection and planning processes support a preference for urgency. Data for evaluating need and deficiency parameters are readily available and are collected on a routine basis for all types of improvements. On the other hand, data for the second group of parameters are not collected and evaluated on a routine basis and are often not available or are at best fragmented. For example, socioeconomic and environmental consequences are now evaluated only for proposed new highways and are not available for other types of improvements.

The need and deficiency parameters are also favored over the second group of parameters in terms of objectivity, one of the guidelines for a good priority analysis procedure. Evaluation of the need and deficiency parameters is largely objective and is based on well-established guidelines and standards. The parameters in the second group are generally evaluated on the basis of subjective judgments that may be biased and that may change appreciably from rater to rater. In addition, the impacts and significance of some of the importance parameters are still relatively unknown because these parameters have only been used to evaluate highway improvements for a short time.

The calculations used to determine the two indexes are very similar to those used for the priority index. The priority group index is formed by combining all parameter ratings of the need and deficiency parameters through the following expression:

$$PG_j = \sum_{i \in M_1} A_i R_{ij}^{N_j} \tag{4}$$

where

PG_j = priority group index of project j, and
$i \in M_1$ = parameter i within the set M_1 of pertinent need and deficiency parameters that have weighting factors greater than zero, excluding those parameters with no available information.

The priority group index indicates the relative degree of urgency for a project. The larger the priority group index is, the more urgent is the need for such a project, and vice versa.

The desirability index is calculated by collapsing the parameter ratings of the remaining parameters of continuity, benefit-cost ratio, local opinions, and socioeconomic and environmental consequences. The equation for the calculation of the desirability index is again similar to that of the priority index:

$$D_j = \sum_{i \in M_2} A_i R_{ij}^{N_j} \tag{5}$$

where

D_j = desirability index of project j, and
$i \in M_2$ = parameter i within the set M_2 of pertinent continuity, highway-user-related, human, economic, social, and environmental parameters that have nonzero weighting factors, excluding those parameters with no available information.

The desirability index indicates the relative importance of a project in terms of its benefits and consequences. The higher the desirability index is, the more important is that improvement, and vice versa.

The only significant difference among the calculations of the priority index, priority group index, and desirability index is the definition of the set of pertinent parameters, M, M_1, and M_2, which in turn induces changes in the normalized weighting factors.

The two-index approach is applied by first ranking the projects in each category in order of their priority group indexes or by the first criterion urgency. Several clusters, or priority groups, are formed from this list in such a way that the members of a priority group all have the same general degree of urgency. The priority groups are ordered on their degree of urgency. Projects in the first priority group are all ranked higher than those in the second priority group, which in turn are ranked higher than those in the third priority group, and so on. Within a priority group, projects are ranked in accordance with their desirability indexes or by the second criterion, desirability.

In addition to having a high priority group index, a project can be assigned to the top priority group for another reason. A project with one or more of its need or deficiency parameters rated critical, that is, assigned a parameter rating of 10, is immediately placed in the top priority group. The reasoning is that a project that is urgent enough to have one or more need or deficiency parameters rated critical demands immediate attention and should be placed near the top of the priority list.

It is premature to determine at this point which approach to priority ranking is more appropriate. Extensive testing is needed before any conclusions can be drawn about the relative merits of the two approaches. However, the two-index approach seems to offer more promise because it treats urgency and desirability separately and because it reflects urgent requirements.

COMMENTS ON THE PROPOSED PROCEDURE

The three basic guidelines of objectivity, comprehensiveness, and consistency are essentially satisfied by the proposed procedure. The comprehensiveness of the procedure is ensured by identifying parameters for each type of improvement from a master list of parameters that includes all of the candidates. Only those parameters that were given unfavorable responses by the raters were eliminated. Objectivity and consistency are preserved in the procedure through the need and deficiency parameters, which can be objectively evaluated through well-established guidelines and standards. The two-index approach places more emphasis on these need and deficiency parameters.

The biggest asset of the proposed procedure is the inclusion of intangible parameters. Socioeconomic, environmental, continuity, and state and local inputs are included. These parameters are sometimes more important than the tangible parameters in the evaluation of highway improvements. Their importance is expected to increase with time.

When intangible parameters are evaluated, objectivity and consistency are difficult to achieve. Subjective judgments, which are highly undesirable, tend to change and conform with the current trend of values. Although socioeconomic and environmental consequences have been considered only for about a decade, the impact of these considerations needs no description. The proposed procedure can adapt to value changes by modifying the definitions, units of measure, and criteria values of affected parameters. The weighting factors of the parameters can also be revised and updated to conform with a changing emphasis. However, some objectivity and consistency will have to be sacrificed when the intangible parameters are incorporated.

The fact that the procedure is flexible, simple to use, and adaptable to electronic data processing should not be overlooked. The number, magnitude, and complexity of present highway programs make the task of project programming a monstrous undertaking. Any technical assistance in simplifying this task should be of great help to the programming process.

The procedure also has the ability to evaluate improvements with only fragmented and incomplete information. Parameters that are pertinent but for which there is no available information are treated as if they are inappropriate and are given weighting factors of zero. Then, as additional information becomes available, the projects may be reevaluated based on the new data. The incorporation of traffic volume and estimated cost elements into the procedure is another small but significant addition to the process.

Some drawbacks observed in existing procedures also exist in the proposed procedure, but to a lesser degree. The obscuring of individual parameter criticality by a composite score is partially offset in the two-index approach. No such provision has been devised for the single-priority index approach.

The sufficiency rating approach as used in most existing procedures rates the deficiencies, or sufficiencies, of the highway facilities, but not the improvements themselves. On the other hand, the economic analysis approach rates the importance of the improvement but fails to identify the degree of urgency or criticality. The proposed procedure combines both these aspects by evaluating the criticality with the need and deficiency parameters and assessing the importance and impact of the improvement projects with the remaining parameters. Furthermore, parameters of conflicting interest may be evaluated simultaneously by the procedure.

The procedure may also be extended to include multimodal transportation improvements such as projects in public transit and airport development. The basic framework of the procedure may be retained. The major area of modification is in the redefinition of the evaluating parameters and probably the introduction of some new parameters. New sets of weighting factors, units of measure, and criteria values will also be needed for the evaluation of improvement projects in other modes of transportation.

CONCLUSIONS

A complete framework of a priority analysis procedure was developed. It is not possible to quantitatively evaluate the procedure until extensive testing and calibration have been completed. The procedure will also require considerable review and refinement before it can be fully implemented. Nevertheless, the authors feel that the procedure is good. It is comprehensive. It is certainly a step toward developing a sound priority analysis program.

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