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CONTENTS

FOREWORD

This RECORD contains papers dealing with transportation planning and the allocation of resources.

The first paper, by Carter, Haefner, and Hall, attempts to synthesize systems evaluation techniques that might be suitable in evaluating the socioeconomic, environmental, and political impacts of transportation improvements. The authors conclude that there currently are no general transportation evaluation models that adequately deal with the impacts on all of the groups affected by transportation system improvements.

The next paper, by Demetsky and Morris, looks at the relationships between pedestrian activity and transportation systems. A methodology is proposed in which the frequency of walking trips relates to the quality of the walking environment. Pedestrian accommodations and impedances arising as a result of transportation systems affect the quality of the walking environment. The authors develop a procedure for measuring pedestrian needs and accommodations and the trade-offs in relation to transportation system improvements.

Ryan, Beimborn, and Nedwek compared citizen attitudes expressed through the public hearing process with the results of a survey of persons living near a proposed freeway corridor. The two techniques indicate different attitudes by the public toward the project. Those who appear at public hearings show a nearly unanimous opposition to the project, whereas those surveyed showed mixed views.

In their paper on environmental mapping, Kuhn and Goggin propose a methodology for measuring the ecological impact of highway improvements. Three scales of maps are presented, and analysis, synthesis, and display techniques are discussed.

The paper by Babcock and Khasnabis describes a pilot study to determine the possibility of making realistic predictions of land development, especially at interchanges along controlled-access freeways in North Carolina. An assessment was made of the traffic-generating characteristics of these land developments.

Mead looks at how a state transportation agency allocates transportation funds among a number of regional districts. The author develops some requirements for allocation methods based on the need for more responsiveness to community and environment factors. The paper also analyzes planners' incentives when allocations are based on proposed district programs.

Rogers examines the problem of balancing project costs against revenue targets. He presents a technique developed for balancing project costs and revenues using a computer with a video display terminal that enables engineers to retrieve right-of-way and construction estimates from a data bank.

Agnello's paper proposes a procedure that can be implemented for measuring the length of traffic queues and time loss from traffic congestion. The method is applied to the actual traffic congestion occurring on the Chesapeake Bay Bridge.

Burke and McFarland describe a procedure for estimating accident costs using cost data from studies done in other states. By using such data and weighting them for the Texas accident experience, the procedure yields direct cost estimates for vehicle accident involvements and value of the loss of future earnings per person killed.

In an effort to further refine one aspect of cost-benefit analysis, Bergmann reviews the rate of return approach and the net present worth approach to investment analysis and suggests a refinement in the rate of return approach that yields conclusions more similar to those using the net present worth approach.

INCORPORATING ENVIRONMENTAL IMPACTS IN THE TRANSPORTATION SYSTEM EVALUATION PROCESS

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An increased social awareness and concern for the environment have added to the complexity of transportation decision-making. This paper attempts to synthesize and assess current system evaluation techniques that are potentially suitable for treating socioeconomic, environmental, and political impacts from the location and design of transportation facilities. The relative merits of several numerical techniques are presented through examples. The arrangement and comparisons developed are ultimately generalized into a cost-effectiveness framework, and dialogue with the operational planner is furthered through a general discussion of the decision-making and model choice problem and an overview of current theoretical research efforts in transportation systems evaluation.

•IN THE last several years, the processes of highway location and design have become increasingly complex, particularly in urban areas. Much of the added complexity is due to tremendous increases in population and advances in highway technology coupled with increased social awareness and environmental concern. The political response to these environmental issues at the federal level has resulted in legislative action that specifically deals with the environment as well as in particular sections of highway acts related to environmental impacts. Included in these are the 1969 National Environmental Policy Act, the 1970 Environmental Quality Improvement Act, the 1965 Highway Beautification Act, and the 1966 Department of Transportation Act. Section 4f of the 1966 act placed restrictions on the use for highway purposes of public parklands, recreation areas, historic sites, and wildlife and waterfowl refuges, and the 1969 and 1970 environmental acts require that consideration be made toward the preservation and enhancement of the environment for all federal-aid highway improvements (1, 2). This paper discusses several promising and potentially operational methods for consideration and evaluation of highway location and design decisions with respect to these social and environmental requirements.

ASPECTS OF LOCATION AND DESIGN DECISIONS

The modern highway decision process requires the generation of a facility location and design alternative, prediction and evaluation of the consequences, and accepting, modifying, or rejecting the alternative. Prediction and evaluation are required for the following:

1. Construction and right-of-way costs;
2. User costs of fuel, oil, and wear and tear on vehicle;

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[1] Dr. Haefner was with the Department of Civil Engineering at the University of Maryland when this paper was prepared.

3. Safety costs—accident rates and costs of accidents;
4. Maintenance costs of the facility; and
5. Environmental and social impacts as listed in the Appendix.

Obviously, the decision surrounding such a wide and interacting set of consequences is complex, and evaluation is difficult. Some weighting technique of part or all of the foregoing consequences may be desirable. Thus, the process should be actively involved within a framework containing the following elements:

1. Objectives—The highway decision should be a step toward accomplishing relevant local, state, or federal goals that can be enhanced by improved transportation systems, such as increased safety, lower travel time, lower commodity rates and prices, increased cultural and social mobility, and increased trade between regions.
2. Criteria—Where possible, yardsticks (termed criteria) for measurement of attainment of the above objectives should be employed. Some examples include, for increased safety, accident rate per mvm; for lower travel time, trip time in minutes from point A to point B; for increased trade, tons of commodity x shipped from A to B after facility opening as compared to before.
3. Alternatives—In fulfilling the objectives of improved transportation, it is necessary to develop a reasonable set of highway location and design alternatives, that is, the composites of alignment, profile, right-of-way, cross section, drainage, interchange and intersection configurations, and control types and devices that together form a design and/or location.
4. Resources and constraints—Usually money, time, soil type, original topography and surrounding land use, manpower, engineering designs, and local political pressures and viewpoints can be considered resources or constraints for a location and design problem.
5. Model—An evaluation technique (termed a "model") should attempt to integrate the aspects of the decision within the foregoing framework of objectives, criteria, alternatives, resources, and constraints and yield a set of feasible alternative locations or designs or, if possible, a "best" location or design alternative.

Although many evaluation methods, ranging from conceptual to fully tested and operational, are currently in use or proposed, the utility of these methods depends greatly on the knowledge, experience, and personal values of the evaluator(s). In addition, many of the methods available have application to only limited factors (i.e., user costs and benefits as in benefit-cost analysis) or project situations. The use of an evaluation method does not replace the elements of discussion and compromise needed to achieve a solution that optimizes the public interest. Accordingly, it is not possible at this time to recommend a single method, or combination of methods, for universal application. Although three general groups of techniques—visual, numerical, and combination—have been investigated, only the numerical techniques are described in this paper, which concludes with a discussion of current research and the future outlook for meaningful evaluation modeling (1).

NUMERICAL TECHNIQUES

Ranking Method

The simplest of the numerical techniques that can be used to compare alternate highway improvements is the ranking method (3, 4). In using this procedure, each alternative is ranked with respect to its ability to satisfy the social, environmental, and economic factors under consideration. As shown in Table 1, the effects of the improvement are optimally oriented, a rank of 1 is assigned to the alternative that best satisfies a particular factor, and a rank of n (where n equals the number of alternatives) is assigned to the alternative that is least desirable with respect to the factor.

For impacts that are quantifiable (e.g., number of dwelling units destroyed) the procedure is easily applied. For nonquantifiable factors (e.g., effects on wildlife protection), a rank is assigned by applying judgment on the basis of a pairwise comparison of the alternatives. In either case, the data requirements correspond to the minimum level required for other numerical methods, data consistency rather than precision being of primary importance.

The most prominent disadvantage of the ranking method is its nonlinearity, which fails to distinguish incremental differences among alternatives. This nonlinearity, coupled with the fact that the factors under consideration may not all be of equal importance, generally precludes the analyst from reaching a decision on the basis of rank summation. In a typical case, as shown in Table 2, no alternative will show a clear superiority to all others. This is a reflection of the fact that each alternative was chosen for consideration in the decision-making process because it is superior to other alternatives with respect to at least one of the factors under consideration. As a result, it is frequently not possible to select the best alternative by the ranking method.

The ranking method is useful in the evaluation of minor projects where the null alternative is environmentally undesirable and in the screening of an unusually large number of projects for the purpose of deleting from consideration those projects that consistently rank poorly.

Rating Methods

Two of the inherent deficiencies of the ranking procedure, the nonlinearity of the scale and the varying levels of importance of the factors under consideration, can be remedied, either individually or collectively, through the use of a weighting scheme. Such schemes, in which the alternatives and/or the impact factors are related to an arbitrary weighting scale, are referred to as rating methods (5, 6). Specifically, one of the following methodologies is employed:

1. The impact factors are weighted according to their relative importance to the community; for example, noise abatement may be considered of more importance than preservation of open space. With appropriate weighting, this procedure permits the inclusion of comparatively minor impacts in the analysis.
2. An arbitrary rating scale is established whereby the impacts may be compared in a consistent and linear manner. With respect to land values, a possible rating scheme would be

50 percent increase in value	rating = 1
10 percent increase in value	5
30 percent decrease in value	9

The application of this second procedure is shown in Table 3, where a set of 7 rating scales (for factors A through G) was hypothesized and applied to the data in the previously discussed ranking example. If all of the socioenvironmental factors were of equal importance, it would be possible to reach a decision by summing the ratings for each alternative. Because of the rating convention used in this example, alternative 4, with the lowest summation, would be the most desirable.

The more enlightened decisions that can be made as a result of the rating methods involve additional expense. This expense is reflected by the increased level of effort that must be expended in the data collection and analysis phases. Although achieving homogeneity of scales used in the rating of alternatives may pose a minor problem, obtaining a consensus with respect to the value judgments employed in factor rating is frequently time-consuming and rather difficult. The method has been shown to work satisfactorily when a representative citizen's advisory group is involved. Differences in community values preclude the adoption of a universal factor rating scheme, and therefore each community must evaluate these factors in accord with local situations. However, the additional effort required is normally worthwhile for the evaluation of major improvement projects.

Rank-Based Expected Value

An interesting modification of the ranking method results in the rank-based expected value technique in which both the factors to be considered and the alternatives are ranked.

Table 1. Example ranking of alternatives versus dwelling units destroyed.

Alternative	Dwelling Units Destroyed	Rank
V	0	1
W	2	2
X	20	3
Y	24	4

Table 2. Ranking example for five alternatives and seven factors.

Socioenvironmental Factors	Alternatives				
	No. 1	No. 2	No. 3	No. 4	No. 5
A—Market access (avg. time to county center, min)	5 (20)[a]	3 (16)	1 (12)	2 (15)	4 (19)
B—Level of service (avg. travel speed, mph)	1 (45)	3 (40)	4.5 (36)	4.5 (36)	2 (42)
C—Provision of public service (police response time, min)	4 (10)	3 (9)	1 (6)	2 (8)	5 (12)
D—Disruption (number of homes taken)	2 (12)	3 (14)	5 (40)	4 (20)	1 (4)
E—User costs (annual $, in millions)	3 (1.0)	3 (1.0)	1 (0.8)	5 (1.6)	3 (1.0)
F—Sonic pollution (db at 100 ft)	5 (75)	3 (65)	4 (70)	1 (50)	2 (60)
G—Others (ranked by engineering judgment)	1 (2)	3 (6)	5 (10)	2 (4)	4 (8)

[a]Actual numerical values of factors are shown in parentheses.

Table 3. Example of rating method application.

Socioenvironmental Factors	Alternatives				
	No. 1	No. 2	No. 3	No. 4	No. 5
A	10	6	2	5	9
B	3	5	7	7	4
C	5	4	1	3	7
D	3	4	10	5	1
E	5	5	4	8	5
F	10	6	8	1	4
G	2	6	10	4	8
Summation	38	36	42	33	38

Table 4. Example of rank-based expected value technique.

Socioenvironmental Factors	Rank Order Value	Alternatives				
		No. 1 (0.8)[a]	No. 2 (0.6)[a]	No. 3 (0.7)[a]	No. 4 (0.6)[a]	No. 5 (0.9)[a]
A	7	1	3	5	4	2
B	3	5	3	1.5	1.5	4
C	5	2	3	5	4	1
D	2	4	3	1	2	5
E	6	3	3	5	1	3
F	1	1	3	2	5	4
G	4	5	3	1	4	2
Plan value		63.2	50.4	71.75	50.1	63.9

Note: Rankings are on scale with an optimal orientation different from that shown in Table 2.

[a]Probability of implementation.

Table 5. Example of value matrix application.

Socioenvironmental Factors	Alternatives				
	No. 1	No. 2	No. 3	No. 4	No. 5
A	0	6	20	7.5	2.5
B	9	6.7	3	3	8
C	4	5	10	6	2
D	11.7	10.8	1.7	8.3	15
E	10	10	14	0	10
F	1	3	2	10	6
G	15	9	3	12	6
Summation	50.7	50.5	53.7	46.8	49.5

The former are ranked according to their relative degree of importance, while the alternatives are ranked in the order of their effect on the factors. Application of this method in Wisconsin (7, 8), shown in Table 4, involved the following steps:

1. The ranking of n plan objectives (or factors) in order of importance and assignment of values of n, n - 1, n - 2, . . . , 1 in descending rank order;
2. The rank ordering of m plans (or alternatives) under each objective and assignment of a value m, m - 1, m - 2, . . . , 1;
3. The estimation and assignment of a probability of implementation for each alternative; and
4. Obtaining the score or value of each alternative by multiplying the rank of the objective by the rank of the alternative and the probability, if required, and summing the products for each alternative.

For example, the score of alternative i can be expressed as follows:

$$V_i = P_i(n_1m_1 + n_2m_2 + \ldots + n_nm_n)$$

where

V_i = score of alternative i;
P_i = probability of implementing alternative i;
n_1 = the rank for factor number one; and
m_1 = the rank for plan m for factor number one.

In the example in Table 4, plan 3 has the highest value and is thus the best alternative.

One of the major advantages of the rank-based expected value method is its ease in application. The objectives must be rank-ordered and the rank value of each alternative for each objective must be determined. However, this is easier to do on a relative basis than on an absolute value scale. For small-scale decision situations (i.e., comparison of project alternatives), changes in ranking to test for sensitivity would be feasible. On the other hand, system-wide alternatives would be too large for this to be practical and the development and use of a computer program for sensitivity analysis would be necessary.

Value Matrix

A technique similar to the rank-based expected value method is referred to as the value matrix method (9, 10). Instead of ranking the factors according to their degree of importance, they are weighed with the most important receiving the highest weight. The previously described rating technique is then used to rate the alternatives to show their effect on the factors. The value for an alternative is obtained by summing the product of the weight of each factor and the rating of the alternative for that factor.

Following the itemization of community objectives, this technique involves these steps:

1. Determine the parameter that best measures each objective. Some suggested measures are indicated for the objectives listed for the ranking method.
2. Assign a weight (or utility value) to each objective to reflect community values.
3. Study the parameter chosen to measure each objective and determine the value for each alternative. If this is done on a weighting basis, the alternative that best meets that objective would receive the highest weight, the alternative that is next best in meeting the objective would receive the second highest weight, and so on until the worst alternative (with respect to that objective) would receive the least weight.
4. Select the best alternative. This technique would select the alternative with the highest value as best meeting that particular combined set of objectives, shown in Table 5 as alternative 3.

Utility curves or the combination of utility curves and relative rating may be used in steps 2 and 3 above.

Schimpler and Grecco (10) suggest some modifications in using the value matrix technique. The major change is in establishing weighted community decision criteria by community decision-makers and professional planners acting as the criteria evaluation group or committee. After individual weighting of the various sets of criteria, the entire group meets and is asked to reevaluate their initial weighting.

A significant advantage of the value matrix technique is its ability, in a systematic framework, to handle a mixture of both subjective measures and values from rigorous mathematical techniques.

Desirability Ratings (Utility Theory)

The formal mathematical attributes of "utility theory", which attempt to measure the worth or value of a set of alternatives or objects to an individual or a group, are utilized in a set of techniques referred to as desirability ratings (11, 12, 13).

The desirability of a highway design or location is one's measure of its worth to him. That is, for location and design alternative 1, we associate a value, V_1, which may be in dollars, a value or a scale from 0 to 100, or any other arbitrary scale consistent with the individual's point of view. This method, as an input to other evaluation techniques, seeks to describe such possibilities of arrival at reasonable scales, which are as follows:

1. Location 1 has several impacts a, . . . , n (capacity alteration, change in accident rate, homes taken, businesses taken, pollution emissions, etc.). The decision-maker associates a set of consistent values $V_{1a}, V_{1b}, \ldots, V_{1n}$ with these n impacts. Then the utility or worth of location 1 is $U(1) = V_{1a} + V_{1b} + \ldots + V_{1n}$, which is the sum of the individual values. That is, the utility structure is additive, yielding a final value for the project.
2. Using the same example, $U(1) = V_{1a} \cdot V_{1b} \cdot V_{1c} \cdot \ldots \cdot V_{1n}$, which is the product of the several individual values associated with the several impacts. That is, the utility structure is multiplicative, compounding over the several values attached to individual impacts.
3. If the several a, . . . , n impacts are uncertain, and there exists $P_a, P_b, \ldots, P_n$, where P_i is the percentage chance that a particular individual impact i will occur, the utility structure may be $U(1) = P_aV_{1a} + P_bV_{1b} + \ldots + P_nV_{1n}$, yielding a final "expected value" of location.
4. Finally, in general, $U(1) = f(V_{1a}, \ldots, V_{1n})$, that is, U(1) may be some complex mathematical function of the several individual values, involving addition, subtraction, multiplication, division, or powers.
5. General transitivity of the utilities of several alternatives is assumed; that is, if the value of location 1 is greater than the value of location 2, and the value of location 2 is greater than the value of location 5, then the value of location 1 is greater than the value of location 5.

A major advantage of this procedure is its ability to develop an abstract measurement scale that is relevant to the concerned groups' points of view, and in so doing to allow the combining of the valuation of several independent results of location into simple or complex functional mathematical forms, as required. As a result, it broadens and moves away from the traditional strict monetary evaluation process. To an extent greater than that cited for the rank-based expected value technique, it allows the combination and inclusion of information about uncertainty of impacts into the evaluation process. And finally, it forms a usable and common input into several currently used evaluation techniques.

Notable among the shortcomings of this procedure is the assessment of the values of the impacts associated with a location (i.e., $V_{1a}, \ldots, V_{1n}$), which is often difficult for each concerned group. Likewise, estimation or measurement of the chances of each impact occurring ($P_a, \ldots, P_n$) is often difficult. The most complex task encountered in the application of this technique is the approximation of the appropriate value or utility function for an alternative; that is, is it additive, an expected value, multiplicative, or some complex functional form, and what are its units, e.g., dollars, lives lost, or some final level on a scale whose values range over selected bounds?

In conclusion, the technique in determining basic value or desirability of a location has merit in discovering the underlying value structure and broadening the evaluation format. However, efficient use in light of its shortcomings should emphasize simple, readily identifiable functional forms of V(1), logically relatable to the points of view of the concerned groups. Complex functional forms should only be used where a very great amount of certainty exists that the mathematical statement is in fact correct and meaningful in relation to the location process and the groups concerned.

Competitive Decisions

The competitive decision model, popularly termed "game theory", attempts to capture the structure of conflict and citizen values inherent in the location process and the struggle between subgroups to effect the alteration of locations and designs that have adverse impacts. It is presented here for its underlying logic fit in the highway decision process and its insight in structuring groups' and community strategies on projects having a significant set of public impacts. Three general types of game-theoretic models are appropriate (14, 15):

1. A 2-person zero sum game, where two opposing individuals or groups are in conflict, and the negative impact on one group is equivalent to the positive impact on the second group.
2. A 2-person open sum game, the same as above except that the amount lost by one group is not identical to the amount won by the other.
3. An n-person open sum game, where there are several groups in conflict, each encountering different losses or gains associated with various combinations of impacts.

In all of the above contexts, each group assesses several location alternatives and supports the acceptance of them to a greater or lesser extent, depending on their value structure and the opposing pressure being exerted for each of the alternatives by other community groups. Where possible, formal solutions to the structures yield a relative measure of support that each group involved in the location process should attach to each alternative to minimize their losses, considering similar maneuvering of emphasis by other groups. Under the current planning process, such support or pressure occurs through the public hearing process, appropriate planning or public works commission meetings, or informal expression of the group's point of view to responsible professional and public officials.

The significant advantage of this technique, in spite of its mathematical and computational complexity, is its ability to adequately structure the citizens' group political and public hearing process and the underlying community power struggle in location decisions as well as in the final implementation and construction phases. As a practical logic framework for the resolution of locational conflicts and insight to forces behind implementation of highway construction, it can be an excellent tool.

DISCUSSION OF THEORETICAL RESEARCH ISSUES

Throughout this paper, review and analysis have been undertaken of evaluation techniques that illustrate a variety of methods for combining knowledge about consequences of highway location and design and weighting these in some manner. This section attempts, in a general manner, to discuss theoretical research techniques currently under investigation. These techniques expand on those already presented and make their solution more straightforward. In addition, they may allow for refinement as additional consequence information becomes available or permit clearer interaction between the community and technical subgroups involved.

One such research technique relates to the alteration of general evaluation formats to encourage response on goals and objectives at the outset of the design process and use of appropriate techniques to subsequently respond with only the best solution relating to these goal and objective statements (16). Previously, evaluation has followed the concept of

Reject or Modify		Step No.
	Generate alternatives	1
	↓	
	Predict consequences	2
	↓	
	Evaluate consequences with respect to goal structure	3
	↓	
	Accept	

It should be noted that the objectives related to the provision of improved transportation facilities are brought into the evaluation at Step 3. Recent research has related to changing the order of the evaluation format, developing the following:

Test possible alternative designs related to alternative objectives		Step No.
	Elicit statements of objectives to be met by improved highway transportation	1
	↓	
	Use appropriate levels of criteria related to the above as constraints on design and location	2
	↓	
	Find "best" design related to above constraints	3

The above format, termed "backward seeking" as compared to the previous "forward seeking" approach, uses statements of levels of service or standards as criteria that are compatible with the objectives. Through consideration of these, all alternatives not satisfying any of the stated criteria are rejected, resulting in acceptance of the alternative satisfying the objectives at their highest possible level within the confines of the stated constraints. Research involving this approach is conducted within the general framework of mathematical techniques referred to as optimization theory and/or statistical decision theory.

Another approach utilizes the ability to introduce uncertainty into the analysis and to refine the analysis when increased information is available. Many of the consequences of highway improvement, their costs, and their value to the community are not known with 100 percent certainty. Hence, recent research has focused on the parameters $P(I_j)$, the probability that an impact of type j will have a relevant reasonable level I; $P(V_j)$, the probability that the community will place a relevant value or worth of V on it; and $P(C_j)$, the probability that it will cost an amount C to alter or arrive at the level I.

Obviously, as more information is gathered through research on impacts and their relation to communities, $P(V_j)$, $P(C_j)$, and $P(I_j)$ should change (17). Hence, Bayesian statistical techniques employing increased information such as historical or laboratory experiments in the community can be used to update the probabilities from time to time, yielding new $P'(V_j)$, $P'(C_j)$, and $P'(I_j)$ as revised estimators of appropriate probabilities related to impacts.

A third approach relates to increased research to develop measuring techniques for inducing individuals' valuation of impacts. Emphasis in this paper has been on the examination of methods that enable individuals or groups to place a value on the consequences of an alternative (18, 19). Continuing research effort is being made to select appropriate interviews, questionnaires, and attitudinal or preference measurement

Table 6. Typical cost-effectiveness analysis of alternatives.

Alternative	Construction and Right-of-Way Cost Net Present Value ($)	Decrease in Corridor Travel Time to CBD (min)	Predicted Accident Rate (acc./mvm)	Dwelling Units Taken	Business Establish-ments Taken
1	1,500,000	12	1.0	100	25
2	1,000,000	10	1.5	60	20
3	700,000	5	4.0	15	14
4	0	0	7.0	0	0

Figure 1. Cost-effectiveness array of impact.

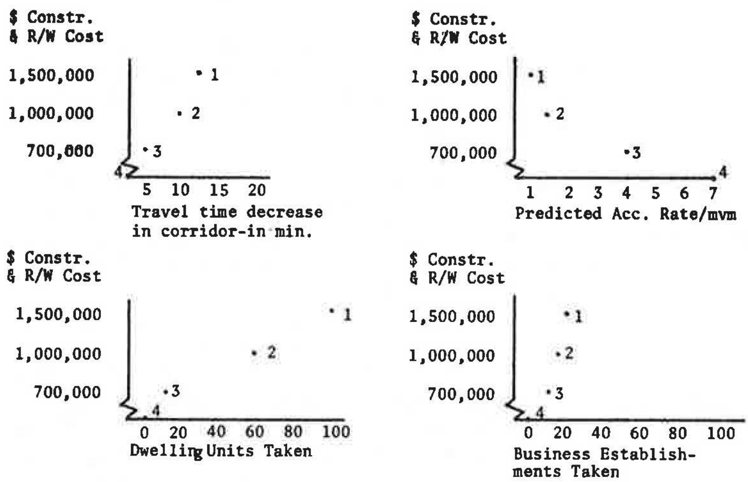
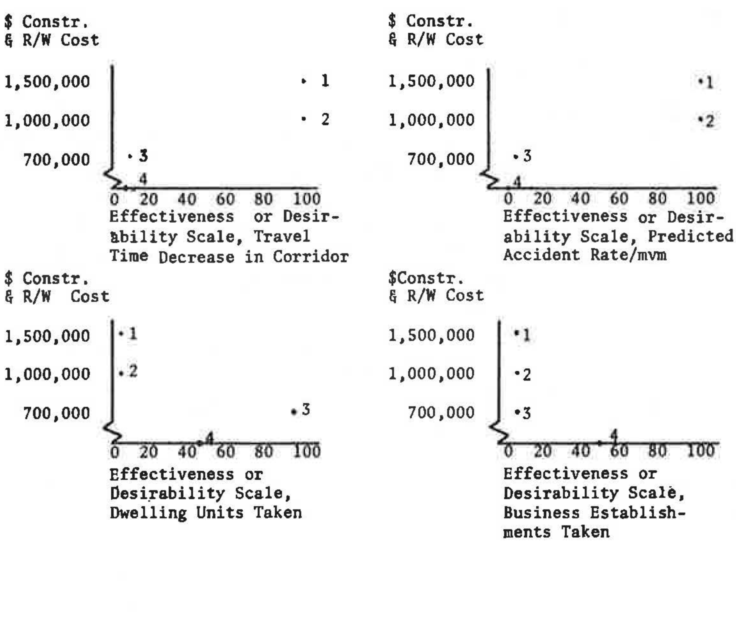


Figure 2. Typical value structure of a community subgroup.



formats that will accurately and logically detect a value structure for levels of consequences relating to the vaguer impacts, such as some of those listed in the first three categories of the Appendix.

A fourth concept calls for increased research in applying the foregoing to the competitive aspects of community location decisions. The value structures in location and design decisions are often revealed prior to or within the public hearing process. As indicated earlier, the primary shortcoming of competitive decision models is their inability to adequately handle processes of several groups in conflict, particularly where each group does not necessarily accrue the same loss or gain due to the location decision. Continuing research emphasis is being placed on efforts to make use of improved measurement techniques in a more liberal interpretation of community conflict (15). This should allow more accurate inclusion of citizen-political interchange and compromise on location and design decisions with respect to the value structure as it truly occurs in a community.

Finally, integration of the various techniques within the broad concept of cost-effectiveness must be considered. The most constructive and representative trend in evaluation research for the appropriate employment of techniques discussed herein exists within the general context of the approach termed cost-effectiveness (20). In this approach, the applied and theoretical research techniques consider positive and negative impacts of a transportation decision for each subgroup, ultimately allowing them to trade off levels of consequences by design type. The crucial impacts for a hypothetical situation where three alternatives for realignment and upgrading of an obsolete facility are being considered are given in Table 6. Each impact is shown in Figure 1, plotted on a capital and right-of-way cost axis.

Alternatively, dwelling units taken could be shown in dollars of tax loss to the community, and businesses taken could have been expressed in total dollar volume of business loss to the area. A community subgroup may put other weightings or interpretations of effectiveness or desirability on these alternatives, as shown in Figure 2.

In light of its value structure, the community group may continue to investigate the alternatives, trading off between alternatives 1, 2, 3, and 4 to ultimately decide on a location and design. It is important to be aware that another subgroup will probably attach substantially different weightings or desirability to these impacts. The values and decisions on alternatives by each subgroup are carried forth into political activity for implementation (council meetings, public hearings, zoning boards, etc.), and there, the trade-offs are reexamined within and across each group's values, resulting in rejection, acceptance, or modification of the location and design alternatives.

CONCLUSIONS

From the material presented in this paper, it should be obvious that no general transportation evaluation model currently exists that can accurately and rationally deal with the subtleties of the impact of any transportation technology on the entirety of groups affected by it. Further, the gap is great between currently available operational techniques and the theoretical questions that must be answered in a rigorous and comprehensive manner to render operationality of evaluation at a more accurate and sophisticated level. Increased effort to this end must be achieved through activities that pursue the following research goals simultaneously:

1. Vigorous theoretical modeling work on relevant community decision and capital investment processes, as discussed in the previous section;
2. Interpretation of such results into a nontechnical library of evaluation techniques for operating engineering and planning personnel; and
3. Effective communication and interchange of ideas concerning the problem structure with operating engineers and planning personnel as well as with the lay community at large affected by highway decisions.

The authors are pursuing such activities through further investigation of the evaluation techniques in specific location and design situations. Problems under study include alignment processes, urban intersection alternatives, transit network problems, and gross regional transportation planning alternatives. The ultimate intent is to develop an operational framework to match appropriate evaluation techniques with system design and location issues.

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REFERENCES

1. Carter, E. C., Haefner, L. E., and Hall, J. W. Techniques for the Evaluation of Factors Relevant to Decision Making in the Federal-Aid Highway Program. Rept. to Federal Highway Administration, U.S. Department of Transportation, Jan. 1972.
2. Carter, E. C., Haefner, L. E., and Hall, J. W. Literature References on Techniques for the Evaluation of Factors Relevant to Decision Making for Highways. Rept. to Federal Highway Administration, U.S. Department of Transportation, Jan. 1972.
3. Criteria for Locating Major Streets and Urban Freeways. Jour. Highway Div., Proc. ASCE, June 1968.
4. Pikarsky, M. Comprehensive Planning for the Chicago Crosstown Expressway. Highway Research Record 180, 1967, pp. 35-51.
5. McHarg, I. L. A Comprehensive Highway Route Selection Method. Highway Research Record 246, 1968, pp. 1-15.
6. Potter, G. A., and Lloyd, I. C. Environmental Resource Analysis. Oregon State Highway Division, 1970.
7. Schlager, K. The Rank-Based Expected Value Method of Plan Evaluation. Highway Research Record 238, 1968, pp. 153-156.
8. Forecasts and Alternative Plans 1990, Volume II. Southeastern Wisconsin Regional Planning Commission.
9. Jessiman, W., Brand, D., Tumminia, A., and Brussee, C. R. A Rational Decision-Making Technique for Transportation Planning. Highway Research Record 180, 1967, pp. 71-80.
10. Schimpler, C. C., and Grecco, W. L. Systems Evaluation: An Approach Based on Community Structure and Values. Highway Research Record 238, 1968, pp. 123-152.
11. Fishburn, P. Decision and Value Theory. Case Institute of Technology, Publications in Operations Research Series, No. 10, 1964.
12. Raiffa, H. Decision Analysis: Introductory Lectures on Choice Under Uncertainty. Addison-Wesley Publ. Co., 1968.
13. Reidesel, G. A., and Cook, J. C. Desirability Rating and Route Selection. Highway Research Record 305, 1970, pp. 16-25.
14. Kaufmann, A. Graphs, Dynamic Programming and Finite Games. Academic Press, 1967.
15. Haefner, L. E., and Redding, M. J. An Analytical Structure of Community Public Works Decision Processes. Papers and Proc. 1972 Joint Conf. of Environmental Design Research Assn. and American Institute of Architects, Irvine, Calif., Jan. 25-27, 1972.
16. Morlok, E. K. A Goal Directed Transportation Planning Model. Northwestern University Transportation Center Res. Rept., Evanston, Ill., 1969.
17. Raiffa, H., and Schlaifer, R. Applied Statistical Decision Theory. Harvard Univ. Press, 1961.
18. Redding, M. J. The Quality of Residential Environments: Preference for Accesibility to Residential Opportunities. Technological Institute, Northwestern Univ., PhD dissertation, June 1970.

19. Shafer, M. T. Attitudes, Community Values, and Highway Planning. Highway Research Record 187, 1967, pp. 55-61.
20. Thomas, E. N., and Schofer, J. L. Strategies for the Evaluation of Alternative Transportation Plans. NCHRP Rept. 96, 1970.

APPENDIX

SOCIOECONOMIC AND ENVIRONMENTAL FACTORS FOR CONSIDERATION IN HIGHWAY LOCATION AND DESIGN

The following lists identify general factors that may be deserving of consideration in the evaluation of a transportation system improvement. Although the lists are reasonably comprehensive, the decision-maker must exercise judgment in determining if other specific or unique factors should be considered in the analysis of a particular project.

For convenience, the factors have been divided into four broad, although not mutually exclusive, categories:

1. Effects on the stationary environment,
2. Effects on the transient environment,
3. Neighborhood and community impacts, and
4. Traditional factors in highway improvement analysis.

Effects on the Stationary Environment

1. Aesthetics
2. Agriculture
3. Aquatic life protection
4. Coastal areas, estuaries, waterfowl refuges, and beaches
5. Farms, forests, and outdoor recreation areas
6. Flood plains and watersheds
7. Mineral land reclamation
8. Navigable airways
9. Navigable waterways
10. Raw material production
11. Scenic enhancement
12. Soil, plant life, erosion, and hydrological conditions
13. Wildlife protection
14. Other topographic factors

Effects on the Transient Environment

1. Air quality and air pollution control
2. Chemical contamination and food production
3. Climatological features
4. Disease and rodent control
5. Health hazards and other dangers
6. Herbicides and pesticides
7. Human ecology
8. Noise control and abatement
9. Radiation and radiological health
10. Sanitation and waste systems
11. Water quality and water pollution control

Neighborhood and Community Impacts

1. Activity patterns
2. Community pride

3. Cultural and recreational opportunities
4. Community protection services
5. Domestic privacy
6. Economic stability of the community
7. Educational systems
8. Employment opportunities
9. Energy generation and supply
10. Historical and archeological sites
11. Housing and building displacement
12. Impacts on other institutions
13. Land values and uses
14. Neighborhood disruption
15. Personal and community identity
16. Population distribution
17. Preservation of open space
18. Property tax base
19. Relocation assistance
20. Special impacts on low-income areas
21. Utility services
22. Visual quality of the environment
23. Zoning regulations

Traditional Factors in Transportation Improvement Analysis

1. Business and trade
2. Congestion in urban areas
3. Construction material availability
4. Disruption during construction
5. Existing transportation system
6. Facility appearance
7. System costs and system economics
8. International implications
9. Land access
10. Low travel costs
11. Modal choice and compatibility
12. Multiple use of highway rights-of-way
13. National defense
14. Regional comprehensive planning
15. Special impact on regional jurisdictions
16. Tourism
17. Transport system reliability
18. Transportation and handling of hazardous materials
19. Transportation safety
20. Travel convenience and efficiency

STRUCTURING AN ANALYSIS OF PEDESTRIAN TRAVEL

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Pedestrian characteristics and physical elements instrumental in shaping walking activity are used to develop a systematic analysis of pedestrian travel. The methodology provides a generalized supply-demand conceptualization of the problem based on pedestrian needs and accommodations (or impedances) and derives a strategy to show that the frequency of walking trips is related to the quality of the walking environment. Trip characteristics define the needs of various socioeconomic pedestrian types. The influential elements of the walking system are stated in terms of accommodations, such as overpasses, pedestrian tunnels, or lighting along walkways, and of impedances arising from high traffic volumes or the barriers posed by the roadways themselves. Trade-off effects between these two major factors establish an index of the quality of the walking environment. Procedures for gathering field data to quantify pedestrian needs and accommodations are proposed, and graphical means of using the information to measure the impact of transportation projects on pedestrian mobility are illustrated. Specific data sought are attitudinal survey information on walking incentives and quantitative measurements of walking accommodations. It is envisioned that the systematic procedures proposed can be incorporated into the highway planning process to improve pedestrian conditions.

•IN recent years, pedestrian travel has received relatively little attention from planners. Although modern engineering has provided technically efficient highways and is in the process of creating advanced ground rapid transit and innovative air travel systems, the means of anticipating and accommodating pedestrian needs remain primarily an art (1). Major transportation studies have, as a rule, treated pedestrian travel in a secondary fashion as an element of vehicular trips, since walking trips have not been goal-related (2). These transportation analyses have served the purposes for which they were intended, but today an awareness of the many indirect impacts of transportation projects requires that planners anticipate certain environmental consequences in order to check ill effects. Accordingly, the achievement of broader social objectives demands that measures be taken to lessen the impact of new roadways on the local activity that sustains residential and business neighborhoods.

THE CASE FOR PEDESTRIAN TRAVEL

A major component of the neighborhood system that must be acknowledged consists of the forces acting on those people who, because of their geographic location, age, economic status, or physical condition, must rely on walking as a primary means of mobility. In most instances, the benefits of a new or improved transportation system do not really apply to these groups. It is also quite common that vehicular way facilities may become walking impedances to the same people they are cited to benefit (3, 4). Such a situation propagates short auto trips as substitutes for journeys previously accomplished on foot. Although this facet is appreciated by highway engineers and urban

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planners, little information is available with which to measure local transportation requirements.

A synthesis of the total transportation picture to include the needs of the dependent pedestrian as well as to encourage the volunteer walker requires a knowledge of pedestrian attitudes and habits. In order to examine these aspects, it is necessary to recognize and measure factors in the physical environment that influence people to walk or not to walk for various purposes. Consider the neighborhood environment of the urban poor, which creates the risk of assault, rape, theft, and harassment by criminal elements. Here lighting, good sight distances, maximum exposure, and security devices may constitute significant travel aids (5). Also, the aged, the very young, and the handicapped require special attention in the design of curbs, stairs, ramps, handrails, etc. In these cases the evaluations of existing pedestrian facilities, particularly newer ones, can be an important source for new planning and design data (6). This conclusion appears valid since measurements on the psychological and physical dimensions of the walking system components, along with the influences of larger structures such as tunnels and bridges, may reveal new or improved criteria. Finally, the frequency of travel on pedestrian overpasses, walking volumes, and walking patterns must be examined to determine the benefits of implementing pedestrian travel aids.

In parallel with the effects of pedestrian accommodations on walking, the barriers to non-vehicular travel created by new highway facilities must be ascertained in order to establish the types of facilities required to nullify constraints on walking. For example, the separation of the residential and commercial components of a neighborhood by a highway may cause significant hardships on those without access to an automobile.

OBJECTIVES

The following major areas are selected for structuring the goals of a systematic analysis of pedestrian travel:

1. The special needs of pedestrian groups who must rely primarily on walking as a means of transportation;
2. The impact of newly constructed transportation works on pedestrian travel patterns and on living habits;
3. The degree of success of existing pedestrian facilities; and
4. The attitudes, including a hierarchical ranking, of various socioeconomic pedestrian types with regard to their walking accommodations.

These goals can be further synthesized to state a set of elements that underlie any pedestrian situation:

1. Pedestrian needs—These needs are the reasons or demands for walking that are associated with pedestrian subgroups. The major objective here is the quantification of pedestrian demands.
2. Pedestrian accommodations—Accommodations are herein designated as conveniences (or impedances) to walking. These factors represent the supply counterpart to the demand described in 1 above.

The aforementioned factors are now taken to provide the core elements in the design of a methodological framework for analyzing the pedestrian transportation problem.

METHODOLOGY

General Development

Many fundamental concepts, theories, and models that have been applied to the analysis of vehicular travel can be utilized to develop a framework for studying pedestrian activity. In any given environment, pedestrian needs and movements are hypothetically related in various degrees to certain trip-maker characteristics, trip factors, and the elements of the walking environment (somewhat analogous to the use of transportation system characteristics in conventional urban transportation planning). The following is a tentative listing of the typical dimensions that provide a basis for monitoring and analyzing pedestrian movements:

Functional Classification

1. Local (all walking)
2. Interzonal or multimodal (of which the walking portion is considered a separate mode)
   a. At trip origin
   b. At trip destination
   c. At vehicular transfer points

Trip-Maker Characteristics

1. Age
2. Auto ownership (individual or household level)
3. Family size
4. Handicap level
5. Income level
6. Sex
7. Type of neighborhood
8. Location of residence relative to CBD

Trip Characteristics

1. Trip purpose
   a. Work
   b. Shopping
   c. Visit friends
   d. Recreation
   e. Personal business
   f. Religious
2. Time
   a. Season
   b. Day of week
   c. Time of day
3. Trip length
   a. Distance
   b. Time in transit

Walking System

1. Obstructions or barriers to pedestrian movements created by freeways and other high-volume roads (impedances)
2. Structures, signals, laws, etc. to accommodate pedestrian movements and/or alleviate pedestrian-vehicle conflicts (accommodations)

The functional classification listed above examines the walking trip in two specific contexts: the local trip (typically in an individual's residential environment) and as the component of a vehicular trip. The latter type of pedestrian movement defines the walk to a residential collector vehicle and the journey from a terminal (parking lot, bus station, etc.) in a major activity center, particularly the CBD.

These dimensions are now implemented to establish the nature of the demand for walking trips, the impedances on such movements by highways, and the effects of providing accommodations that make more opportunities accessible via walking. The demand for walking travel is postulated to derive as follows:

$$D_w = F(FC, TM, TC, WS) \quad (1)$$

where

D_w = a measure of individual walking demand (number of trips per unit time, probability of walking, etc.) for conditions FC, TM, TC, WS;
FC = the functional class of the trip;
TM = the characteristics of the trip-maker;
TC = the trip characteristics; and
WS = an index of the quality of the walking environment.

Equation 1 provides a mechanism for conceptualizing the various interrelationships that describe the pedestrian problem.

The Walking Environment

The facility for quantifying the impacts of highways and pedestrian accommodations on the walking behavior of the different travel classes (TM, TC) is based on the following hypothesis: Highways have negative impacts on the walking environment while pedestrian accommodations enhance the potential for walking travel.

Hence, the quality of the walking environment is derived from a net figure that accounts for the positive factors (accommodations) and negative factors (impedances):

$$WS = F\left(HY^{-}, AC^{+}\right) \qquad (2)$$

where

WS = index of the quality of the walking environment;
HY^{-} = the impedances caused by highways; and
AC^{+} = the pedestrian accommodations provided.

Equation 2 provides a basis for an index that can be used to compare the quality of different walking environments and/or to monitor the changes that take place over a period of time in a particular pedestrian system.

Now a method for specifying how the walking environment enhances or prohibits interactions between individual and urban opportunities is introduced:

$$d_{avg} = \sum_{w=1}^{N} \frac{D_w}{N} = \sum_{w=1}^{N} F_w(FC, TM, TC, WS) \qquad (3)$$

where

d_{avg} = the average number of walking trips or average number of person walking-miles for a given category of the explanatory variables that is observed in a given environment;
D_w = walking demand for a specific category; and
N = total number of categories.

Equation 3 gives the average walking activity observed in a given urban area (e.g., person-miles of walking per day). If the socioeconomic dimensions (TC, TM) and areal characteristics (FC) are held constant, Eq. 3 becomes

$$d_{avg} = F(WS) = F\left(HY^{-}, AC^{+}\right) \qquad (4)$$

Thus, individual walking activity is directly related to the quality of the walking environment.

The preceding functional development, which establishes important relationships and dimensions of pedestrian travel, is now employed to establish an experimental design for conducting a diagnostic analysis of pedestrian activity. It is premature at this time to develop forecasting tools for pedestrian analysis at the stated level of detail since the state of the art is relatively primitive compared with that for vehicular travel. It is thus appropriate that initial walking analysis, as suggested in the next section, be concerned with describing behavior in order to propose meaningful hypotheses on the subject.

EXPERIMENTAL DESIGN

Analysis of Pedestrian Needs and Accommodations

In order to correlate the findings concerning needs and accommodations, pedestrians are classified according to their environmental-socioeconomic status. Individual attitudes toward walking needs and accommodations are hypothesized to be similar within certain groups (6). Age, sex, and income are typical factors for group identification but further subclassification may be necessary or desirable. Once pedestrian categories have been determined, trip-makers in the data sample are assigned to a category and then characterized by the following attributes:

1. The total number of trips made from their domiciles per week;
2. The number of walking trips they make per week in each of several walking purpose (need) categories such as family shopping, personal business, employment commuting, recreation, etc.; and
3. Their attitudes with regard to accommodations for walking such as safety, comfort, convenience, and aesthetic considerations.

The need analysis proceeds with a comparative study that utilizes the following input data:

p_{ij} = number of type i need walking trips observed for pedestrians in group type j;
P_j = total number of walking trips observed for pedestrian in group j;
t_{ij} = total number of type i need trips observed for pedestrian in group type j;
T_j = total trips of pedestrians in group type j;
m = number of different type trips;
n = number of pedestrian type groups;
α_{ij} = percentage of walking type trips i, relative to the total walking trips made by group j; and
γ_j = percentage of total walking trips for group j relative to the total trips made by group j.

Thus,

$$P_j = \sum_{i=1}^{m} p_{ij}$$

$$T_j = \sum_{i=1}^{m} t_{ij}$$

$$\alpha_{ij} = 100\ p_{ij}/P_j$$

$$\gamma_j = 100\ P_j/T_j$$

The summary results of this interpretation are shown in a walking need versus pedestrian type index matrix in Figure 1.

In a similar fashion, an accommodation index matrix can be derived for various pedestrian groups. Relative weights for accommodations that facilitate and encourage walking, as perceived by the different pedestrian groups, are determined from attitudinal surveys. The output of this analysis is then a series of normalized weights, β_{ij}, which indicate the perceived importance of accommodation i to pedestrian group j.

The format for this data interpretation is shown in Figure 2. This chart indicates physically desirable aspects according to orders of importance and can be employed to provide a set of indicators for any particular neighborhood or areal situation.

Figure 1. Pedestrian needs versus type index matrix.

		PEDESTRIAN TYPES					
		1	2		j		n
		Urban Handicapped	Urban Housewife		Type j		Suburban Businessman
Needs	1. Shopping	23	38		:		12
	2. Personal Services	16	21		:		27
	3. Business Commuting	2	6		:		53
	4. Visitations	8	11		:		3
					:		:
	i Activity i	. .	. .		α_{ij}		α_{in}
							:
	m Recreation				α_{mj}		α_{mn}
	TOTALS (%)	100	100		$\Sigma\alpha_{ij}$		100
	Walking Trips ÷ Total Trips (%)	93	86		γ_{ij}		14

Figure 2. Pedestrian accommodation versus group index matrix.

		PEDESTRIAN TYPES					
		1	2		j		n
		Urban Handicapped	Urban Housewife		Type j		Suburban Businessman
Accommodations	1. Crosswalk Controls	25	36		:		21
	2. Street Lighting	8	48		:		8
	3. Ramps and Railings	57	16		:		2
	4. Color and Cleanliness	5	12		:		63
	: :				:		:
	: :				:		:
	i Activity i	. .	. .	. .	β_{ij}	. .	β_{in}
	p Visibility				β_{mj}		β_{mn}
	TOTAL (%)	100	100		$\Sigma\beta_{ij}$		100

Analysis of Impact of Highways on Pedestrian Mobility

By utilizing data from neighborhood environments that have been impacted by a transportation project, comparisons can be made with similar neighborhoods that have not been so affected. The index for such comparisons might be average person walking-miles per unit time for different trip-makers and/or different trip types. These statistics could then be used to derive a relationship between walking behavior and the amount, or lack, of certain physical accommodations that affect foot travel. This information, therefore, provides a means of measuring the impact of highway development on continued pedestrian accessibility to former facilities or activities.

This analysis can be taken at either of two levels; the first is indicative of inter-area comparisons, while the latter represents a more detailed diagnosis of a local problem. The former method simply takes a statistic of the observed areal travel (d_{avg}) and plots it versus the related walking environment quality index. A hypothetical example of this approach is shown in Figure 3, where k designates different study areas. For example, if the trip-maker and trip characteristics are held constant, inter-area comparisons will relate the change in walking behavior ($\Delta N_{1,\ 1-2}$) caused by the difference in quality of the walking environment ($\Delta WS = WS_2 - WS_1$). Also, this model can be employed to specify changes between the walking behavior of different groups or different trip types in a given area. Here, the walking quality remains constant (e.g., WS_1) and a particular TM or TC dimension is varied [e.g., $(TM, TC)_1$ to $(TM, TC)_j$]; $\Delta N_{1-j,\ 1}$ is then a measure of the different travel habits within a certain area.

Similar information that derives from before-and-after study in a single area can alternatively be examined in a more detailed fashion. Here the cross-sensitivity between pedestrian travel strata is represented in view of changes in a single walking environment. For example, Figure 4 shows the before-and-after behavior of typical groups resulting from a highway project. Thus, the difference between the a and b level represents the travel demand that the provision of pedestrian accommodations must induce in order to alleviate the disturbances to foot travel created by highway development.

Data Requirements and Acquisitions

The attainment of the basic goals pertaining to pedestrian analysis depends, to a large extent, on the quality of the acquired data. It is imperative that information be obtained from similar type individuals in differing environmental circumstances as well as from different pedestrian types in the same environment.

A broad data base is necessary in order to gain knowledge on pedestrian behavior. The perceived data sources consist of the following:

1. Attitudinal travel information from individual and group interviews;
2. Existing data on walking behavior in different environments; and
3. Field evaluations of walking environments.

In the first case, information is required in order to determine how individuals perceive the role of walking in their life-style, their perceptions of the various elements that compose the pedestrian system, and their walking and travel habits. The primary mode for soliciting judgment data is an attitudinal questionnaire designed to determine the most critical factors underlying a stated decision and the relative weights the individual associates with each measure.

In this case, certain samples of individuals should be selected from different walking environments and asked to meet as a study group at a local public building. The meeting is designed to subject the sample group to the following tasks:

1. Fill out an information form citing pertinent socioeconomic and travel data.
2. Participate in an attitudinal survey to provide judgments on the following: (a) perceived deterrents to walking, (b) walking travel needs, and (c) hypothetical situations clearly presented via visual aids.
3. Fill out a checklist for all trips taken during a specified time period.

Figure 3. Inter-area comparison of walking.

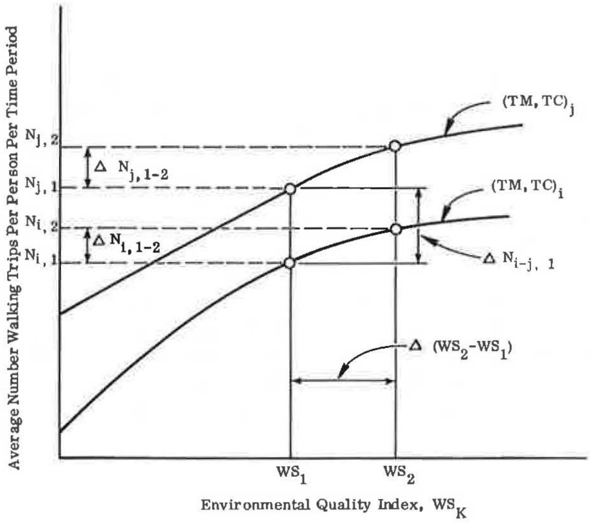


Figure 4. Local analysis of changes in walking activity.

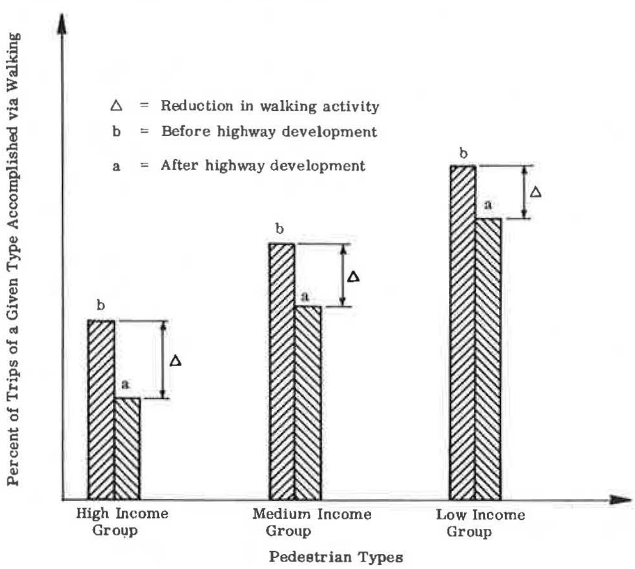
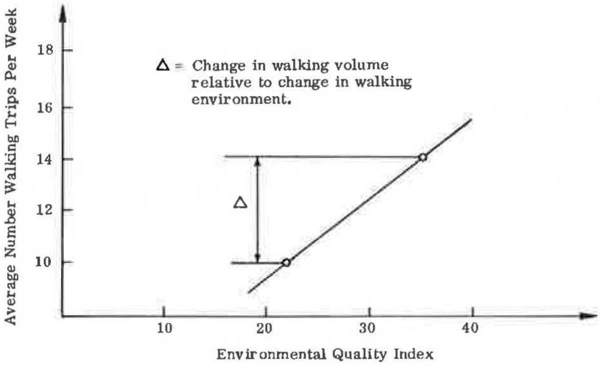


Figure 5. Example environmental-walking impact analysis.



Of particular significance is the checklist to be filled out for each trip taken by the individuals in the sample group. This checklist is proposed to strengthen the diary approach to obtaining longitudinal travel data. This method will guarantee consistency between the responses of various individuals, which becomes a problem when comparing the information in diaries. Also, besides being more objective than diary notes, the checklist data can be processed more efficiently.

The second type of data derives from existing sources to provide rapid data on pedestrian activity (i.e., origin-destination surveys, parking studies, etc.). This information would supplement in-house travel data.

The final information required concerns the selection and measurement of elements of the walking environment that accommodate or constrain pedestrian activity. Surveys must be made in order to define those factors that determine the quality of the walking environment. Once these elements are determined, the appropriate engineering measurements can be made along typical walking routes in any study area. The measures anticipated here include the type of quantifications of pedestrian facilities outlined in the Traffic Engineering Handbook (7).

IMPLEMENTATION OF STUDY METHODOLOGY

The program described is quite broad and is intended to apply to any specific walking travel analysis. However, two primary subsets of walking population are inferred to be of particular interest here, namely (a) those who are most dependent on walking for mobility and (b) those vehicle trips in suburban or other residential areas whose needs could be met by walking if satisfactory accommodations for pedestrian trips were provided.

For example, initial study will concentrate on only those socioeconomic classes and districts that exhibit the above circumstances. In the first case, the travel behavior of low-income groups (high probability of no automobile being available) and the aged and handicapped (unable to drive) is examined. For the latter problem, the inhabitants of residential communities that are spatially close to such trip attractions as shopping centers and recreational areas but face physical barriers that discourage walking, such as freeways, are considered.

Although the scope of the total walking population has been reduced, it is assumed that any changes in the walking environment that will enhance or deter the pedestrian movement of the stated subpopulations will have similar impact on total walking travel, although possibly in varying magnitudes for different socioeconomic classes (6). It is also noted that the scope of analysis required of the physical walking environment is not reduced by limiting the type of trip-makers studied.

Example

A hypothetical example of the application of the methodology discussed in this paper and summarized in Figures 1, 2, and 3 is given to illustrate the procedure. Assuming that the appropriate data (as described earlier) are available, the processed results give the pedestrian need versus type matrix for two areas and provide the following summary statistics:

Area 1—Average number of shopping (TC) trips per week for low-income individuals (TM) accomplished by walking was 10.
Area 2—Similar statistic is 14.

The respective accommodation versus type index matrices give

Area 1 index = 22
Area 2 index = 35

Figure 3 is next used to analyze the impact of the walking environment on these two identical socioeconomic and trip categories. This is shown in Figure 5, where a linear relation is given for the trade-off between walking and pedestrian environment.

The preceding example is quite elementary, but nevertheless the practical application in the planning for pedestrians is indicated.

SUMMARY

This paper presents a comprehensive framework to guide study and analysis of pedestrian needs and accommodations. The development derives from current transportation planning principles, which are utilized to synthesize the various components of a pedestrian-environmental system. It is envisioned that these systematic procedures can immediately be incorporated into the highway planning process.

The format has been designed to show variations in walking behavior among different trip types and travel groups in different walking environments such that the results can be used to guide policy decisions in any urban area. The anticipated findings can serve as preliminary guidelines for assessing pedestrian needs and may provide the necessary hypotheses to develop more refined techniques in forecasting changes in pedestrian behavior when walking environments are altered.

REFERENCES

1. Stuart, D. G. Planning for Pedestrian. Jour. American Institute of Planners, Vol. 34, No. 1, Jan. 1968.
2. Morris, R. L. Downtown's Forgotten Man (and Woman). Nation's Cities, Vol. 5, No. 12, Dec. 1967.
3. Carp, F. M. Pedestrian Transportation for Retired People. Highway Research Record 356, 1971, pp. 105-118.
4. Jacobs, G. D., and Wulson, D. G. A Study of Pedestrian Risk in Crossing Busy Roads in Four Towns. Ministry of Transport, RRL Rept. LR 106, London, 1967.
5. Are Pedestrian Crosswalks Safe Enough? Civic Administration (Canada), Vol. 18, No. 5, May 1966.
6. Roberts, D. C. Pedestrian Needs—Insights From a Pilot Survey of Blind and Deaf Individuals. Public Roads, Vol. 37, No. 1, June 1972, pp. 29-31.
7. Traffic Engineering Handbook. Institute of Traffic Engineers, Washington, 1965, pp. 108-141.

A REVIEW OF THE PUBLIC HEARING PROCESS AS A MEANS OF OBTAINING CITIZEN VIEWS AND VALUES

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ABRIDGMENT

•THE importance of citizen input to the process of highway planning is well recognized as being essential to the development of proper designs of these facilities to best meet the needs of the people they serve. In the past this input of citizens concerned with a project has come mainly through their elected officials and through the public hearing process. Recently, however, the level of citizen opposition has increased in many cities and has raised serious questions as to the adequacy and accuracy of the public hearing process as a means of gaining citizen input into the planning process.

Previous work at the University of Wisconsin—Milwaukee (1, 2) investigated the feasibility of social diagnostic techniques as a means of gaining understanding of citizen views and values in the transportation planning process. This was done through conducting a home interview survey of residents living in or near the proposed corridor of the northerly extension of the stadium freeway in Milwaukee County. The purpose of this paper is to compare attitudes toward the project as expressed at the public hearing (obtained from an analysis of the hearing transcript) with those obtained from the survey and the use of social diagnostic techniques.

The overwhelming feeling of those persons who presented testimony at the hearing was one of opposition. Only 5 of the 14 organizations and 3 of the 42 individuals who testified orally at the hearing supported the project. Of those who submitted written testimony, only 6 of the 15 organizations and 2 of the 69 individuals were in support of the project. Finally, 5 petitions containing 4,183 signatures were received supporting the project while 9 petitions containing 21,487 signatures opposed the project. Among the concerns expressed most often by individuals in opposition to the project were its adverse effects on property through the taking of homes and inadequate compensation for them (33 persons), the increases in air and noise pollution levels (21 persons), the loss in tax base (23 persons), and the need for better mass transit (21 persons).

The picture that emerges from the survey is quite different. Of those surveyed, 40 percent approved of the northerly extension of the stadium freeway, 45 percent disapproved, and 15 percent had no opinion. This can be contrasted with that of the public hearing, where 95 percent of the individuals testifying opposed the project. The survey further indicated that the respondents had a generally low opinion of highway planning and felt that they were not being told enough about what was being planned. The respondents generally felt that public hearings were an effective means of expressing objections to a proposed project, but only a small portion of them have actually participated in such a hearing.

From these results it is evident that the public hearing did not present an accurate picture of citizen attitudes and values. This finding implies an essential need to conduct well-structured parallel surveys of the residents of an area affected by a project. Such surveys can be utilized to establish "bench marks" or "datum points" of community views that can be used to gain a fuller understanding and appreciation of the views

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expressed at a public hearing. The findings also have further implications on the formulation of action programs for citizen involvement in the transportation planning process, namely, a need to gain an accurate understanding of community values if such programs are to be successful. Finally, the results also lend credence to the suggestions by others (3,4) of the need to modify the public hearing process and to open up more mechanisms for greater citizen involvement in planning efforts.

ACKNOWLEDGMENTS

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REFERENCES

1. Ryan, C. The Views and Values of the Community Affected by a Major Transportation Project. National Technical Information Service, Rept. PB 210 563, Jan. 1972.
2. Ryan, C. R., Nedwek, B. A., and Beimborn, E. A. An Evaluation of the Feasibility of Social Diagnostic Techniques in the Transportation Planning Process. Highway Research Record 410, 1973, pp. 8-23.
3. Walton, L. E., and Saroff, J. R. Proposed Strategy for Public Hearings. Highway Research Record 356, 1971, pp. 26-31.
4. Citizen Participation and Community Values. Highway Research Record 380, 1972.

ENVIRONMENTAL MAPPING: AN ECOLOGICAL METHODOLOGY FOR HIGHWAY IMPACT ANALYSIS

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ABRIDGMENT

Environmental mapping is proposed as an ecological methodology for systematic analysis of highway impact, an important part of the planning process. An exploratory investigation of a forest highway corridor was conducted to demonstrate potential applications. Maps at three scales are presented and analysis, synthesis, and display techniques discussed. The methodology is viewed as a modeling procedure involving the inventory and analysis of the regional ecosystem elements; the synthesis and organization of inventory information through environmental mapping; analysis of environmental impact through modeling techniques; and the communication of environmental inventory and impact information through effective graphics.

•IN addition to the need for meeting the legal requirement for an environmental impact statement, impact analysis of project alternatives is an essential component of the planning process because it provides a means for comparative evaluation of alternatives.

More than 25 environmental impact statements were read by the authors prior to developing the thesis presented here. None was found to contain a modeling approach, and very little graphic material was presented in an attempt to define and quantify environmental elements and anticipated changes; i.e., there was no evidence to indicate "the integrated use of the natural and social sciences" as called for by the National Environmental Policy Act (NEPA).

A study was therefore conducted to examine the potential applications of the principles and techniques of environmental mapping as a methodology to be used in environmental impact analysis and for presenting the information developed in such a manner that diverse groups and individuals can relate to and draw conclusions from it. This latter consideration is especially relevant in that community interaction has been identified as the appropriate means of determining community concerns and establishing significance of impact (1,3).

METHODOLOGY PROPOSED

Geographers, foresters, and regional planners have developed proven regional analysis and modeling techniques, utilizing maps, that are well-suited to impact studies. These methods have been applied previously to route location problems (2,4). As applied to environmental impact studies, the environmental mapping methodology involves

1. Inventory and analysis of the regional ecosystem elements;
2. Synthesis and organization of this information through environmental mapping;
3. Analysis of environmental impact through modeling techniques; and
4. Communication of environmental inventory and impact information through effective graphics.

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The initial step is a thorough survey of all available sources of data for the study area. Maps, aerial photographs, management plans, and other sources are gathered from agencies and individuals having interest or involvement in the area. Through interpretation and evaluation of the data by a professional interdisciplinary team and interviews with knowledgeable citizens, identification of social and ecological systems elements and their significance can be made. In many instances additional field research will be necessary to supplement available data.

Emphasis is placed on the systematic preparation of an ecological inventory of the natural features that are indicators of natural processes. Data are collected for the study area in the following sequence as suggested by Ian McHarg (4):

1. Climate
2. Historical geology
3. Physiography
4. Hydrology
5. Pedology (soils)
6. Plant associations
7. Animals
8. Land use

McHarg stresses this causal sequence of data collection because each succeeding consideration relies on the preceding one to achieve maximum understanding of the entire process.

The second stage of the methodology involves organization and synthesis of the information generated in the inventory into a workable framework. This is a classification process where the data are interpreted and synthesized into a smaller, more workable number of variables, e.g., natural communities, land use classes, areas of pollutant concentration, flow patterns.

An abbreviated model of the existing environment is therefore assembled, with both generalized and critical key elements identified and mapped. Analysis of impact on these environmental elements from human activity (specifically, the construction and use of a highway facility) is made in the third stage through expansion of this model. The analysts interpret the elements individually and, through the "stacking" of transparent overlay maps, study any combination desired in order to clarify interrelationships. In addition, patterns at different points in time are developed and compared, thus modeling the process of change. This property—the capacity to simulate environmental relationships and environmental change—is what makes the model dynamic, i.e., ecological.

An important aspect of this methodology, listed here as stage 4, is the need for effective communication as an integral part of the impact analysis-planning process. The analysts must be able to communicate in order to identify elements and relationships and especially to obtain evaluations of significance.

Environmental mapping not only is useful as a tool of analysis by professionals, but also is a means of effective graphic illustration of facts and judgments. It is therefore an excellent vehicle for achieving informed public participation, especially when combined with attractive and creative use of photographs and other supporting material. One method of achieving this participation is to present maps and aerial photographs at public information stations and meetings, with transparent overlay sheets on which anyone may indicate areas of concern and relevant information.

FIELD STUDY: US-50 FROM PLACERVILLE TO SOUTH LAKE TAHOE

The US-50 corridor study was not a complete testing and evaluation of the modeling approach. The intention of this phase of methodology development was to introduce, discuss, and explore potentials. A complete environmental impact analysis based on the suggested methodology has not yet been conducted. The field study did provide the following:

1. Examples and discussion of how techniques of regional ecosystem analysis through environmental mapping can be used in a forest highway situation;

2. Examples and comparisons of different mapping techniques;
3. Discussion of information sources and problems of data gathering; and
4. Demonstration of how effective graphics can aid communication.

Working at various scales, a series of environmental maps of the US-50 corridor was prepared depicting elements of the ecosystem that might be significantly affected by a highway project.

The following discussion of three of the maps prepared in the field study will serve to demonstrate various aspects of the methodology.

Macro-Area: Rare and Endangered Plants Map

The base for the small-scale, macro-area maps was made from Army Map Service 1:125,000-scale sheets of the region. All information outside El Dorado County (the county containing the study area) was eliminated, and the base map was reduced to the desired dimension of 11 by 17 in. for publication. Each subject map was prepared on a transparent overlay and printed on the base.

The rare and endangered plants map (Fig. 1) demonstrates the following points with regard to ecosystem analysis and environmental mapping:

1. Mapping of a specific natural environment element with special social significance;
2. Small-scale, large-area mapping;
3. Use of black and white with and without added color (originals only);
4. Use of a base map with selected information printed as an ovelay on the base; and
5. Use of private organizations as information sources.

The topic of rare and endangered wildlife species has been prominent for a number of years. A much more recent concern, just coming to the attention of the general public and state agencies, is that of rare and endangered plant species. The California Native Plant Society was founded in 1965 in response to growing concern over threats to the state's native plants posed by the rapid pace of development. Its purpose is to determine which native plants are rare and/or endangered, locate where these species are found, and present these facts to the public.

The accompanying map of rare and endangered plants is the only such effort made for El Dorado County to date. Through discussion with the local Society representative in El Dorado County, the approximate location of those plants currently listed in the inventory was made. Many biologists and resource managers prefer that information on certain sensitive environmental sites remain guarded in order to protect the resources; therefore, the map does not give precise field locations of the plants in question. Its purpose is to indicate the existence and general location of these sensitive areas to be considered early in the planning process. Key habitat for rare and endangered animals could be located in a similar manner.

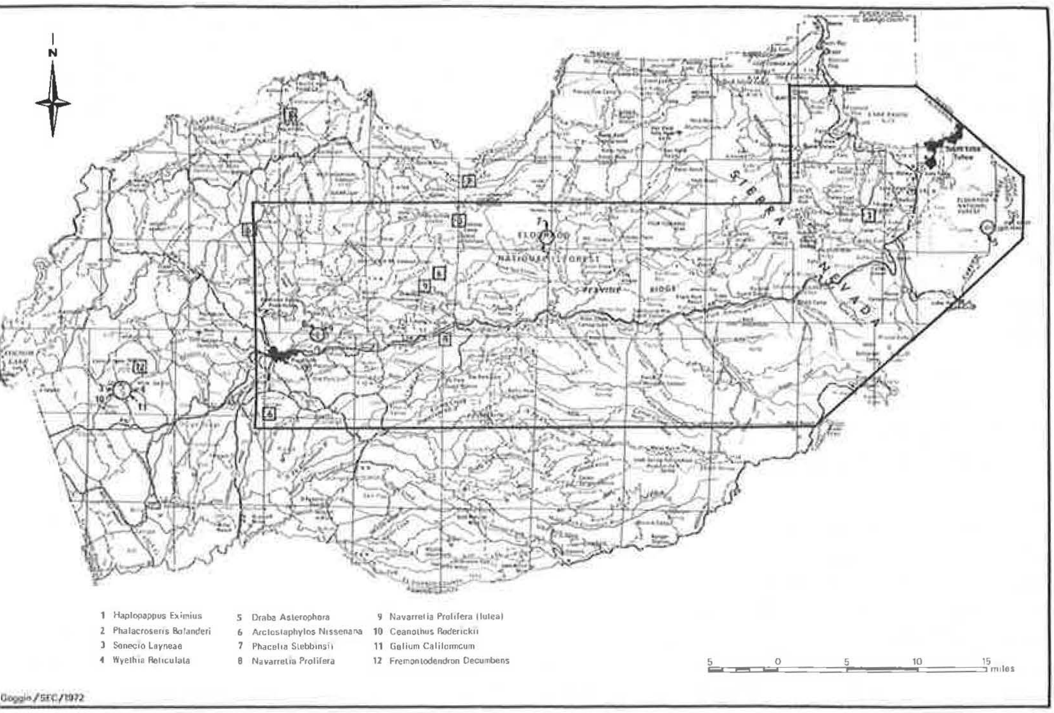
Meso-Scale: Corridor Vegetation Map

The corridor vegetation map (Fig. 2) demonstrates the following points:

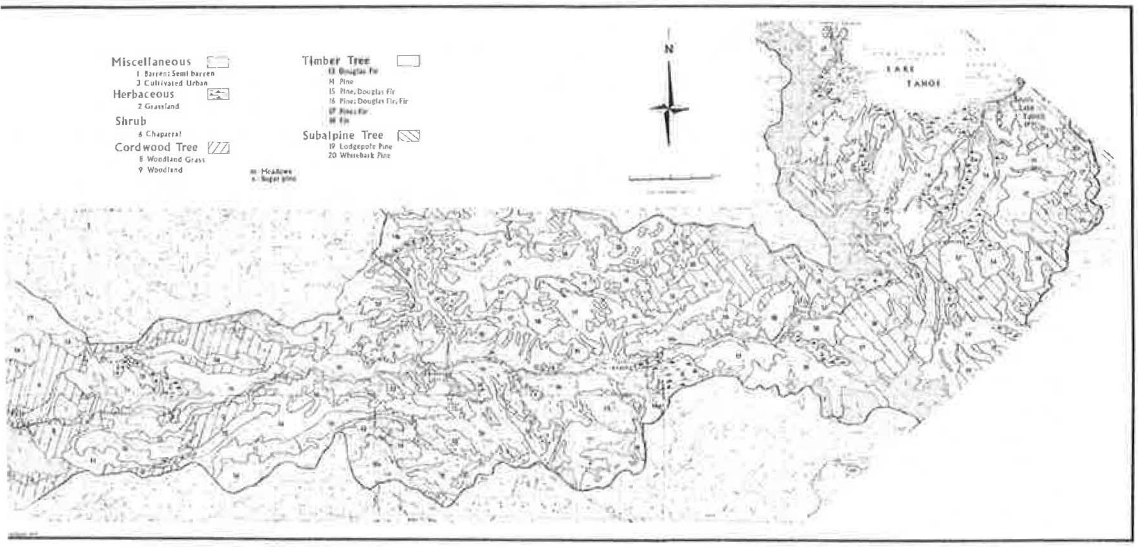
1. Mapping of generalized elements of the ecosystem;
2. Mapping of an entire study corridor at a meso-scale;
3. Use of overlay technique;
4. Use of two colors (originals only); and
5. Use of numbers and patterns to differentiate elements.

The base map was prepared by combining adjacent portions of nine USGS topographic quadrangles of a scale 1:62,500. The subject maps, e.g., vegetation, were prepared on transparent overlay sheets and printed individually on the base map. The base and the overlay maps were printed in different colors. The combined maps were then reduced to an optimum (11 by 24 in.) size for publication. At this size, the scale is approximately ½ in. to the mile and the contour lines are plainly discernible. Meso-scale maps of this nature are best for giving a broad view of the corridor and are of more use in impact analysis than the small-scale maps.

ure 1. Rare and endangered plants.



ure 2. Vegetation types.



The assembling of vegetation data is of great importance in the regional ecosystem modeling procedure. Every example of environmental mapping reviewed includes vegetation mapping, e.g., step 6 of McHarg's inventory procedure. Vegetative cover is an important indicator of ecological relationships and social values such as recreation use, commercial timber production, and wildlife habitat. The vegetation map serves as a focus for discussions with professional resource managers and planners concerning location of habitats or land use.

Micro-Area: Sequential Land Use Map

The sequential land use map (Fig. 3) is a complex of three maps and a series of bar graphs. At this larger (1:24,000) scale more detailed information can be shown for smaller areas. An even larger scale is needed for consideration of such factors as highway design features. The sequential land use map demonstrates the following points:

1. Large scale-small area mapping.
2. Time phase or sequential mapping of environmental change.
3. Use of black and white patterns with added colors (originals only).
4. Aerial photography as a supplementary graphic aid (Fig. 4).

The sequential land use map consists of the same area mapped at three time intervals. The base map was traced from USGS 7½-minute quadrangles, selecting only the major features—roads, rivers, etc. Land use information was then delineated on this edited base map. Distributions were coded in black and white with three additional colors applied later. The colors serve to highlight the land use distributions.

A sequential map series must first show the geographical patterns that precede the present conditions in the environment. This is done by assembling all available information (aerial photos, land use maps, management plans, etc.) indicating patterns at one or more earlier points in time. Next, a map showing the current environmental situation is prepared, with data coming from the same general sources simply updated. By comparing and relating past conditions to present conditions and seeking interpretation of the processes responsible for the changes, a basis from which to project future change in the environment is established.

At all stages of the inventory and impact modeling process, the analysts must seek out and evaluate the observations and judgments of those professionals involved in planning, research, and management of the land and resources in the study area. This is especially true when projecting change. Where conflicting views are noted, in-depth studies will often be required. Some reluctance to provide evaluative information and especially to make projections, will be encountered. Our studies to date indicate that an interviewer will have greater success in obtaining such information when discussions are centered on an environmental model.

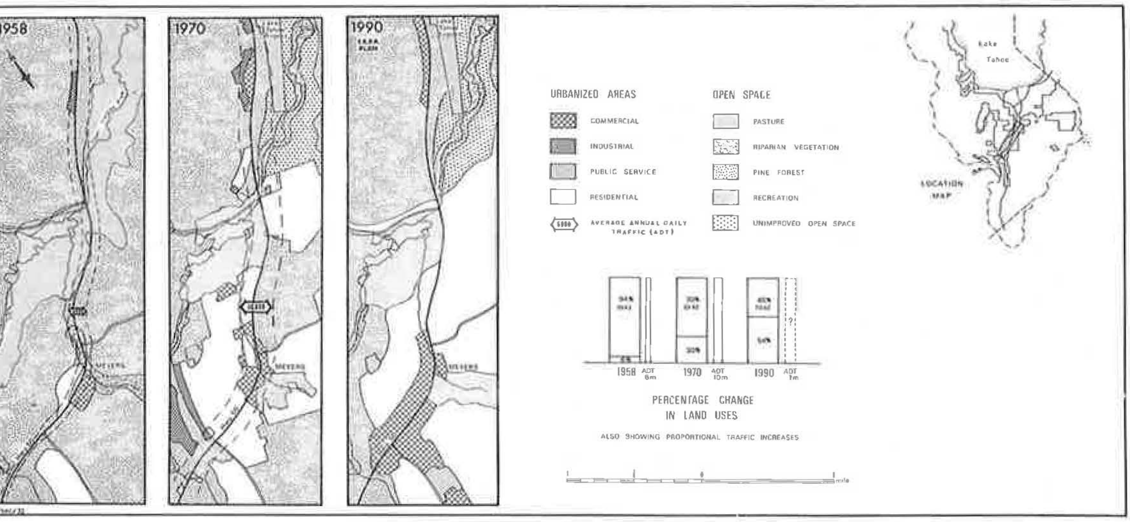
The map showing projected land use patterns was based on the General Plan for the Tahoe Region produced by the Tahoe Regional Planning Agency. As implied by the nam general plan maps include a certain degree of generalization. It is therefore especially important to work closely with those responsible for developing the plans and knowledge able businessmen and property owners who may provide information on potential development not anticipated in a general plan when projecting patterns.

Time-phase mapping of an environment can focus on different social and ecological system elements. For this portion of the corridor, land use classifications were selected for demonstration purposes. For this and other segments, changes in wildlife population dynamics, vegetation, recreation activity, and other elements could be examined and presented in the same sequential manner.

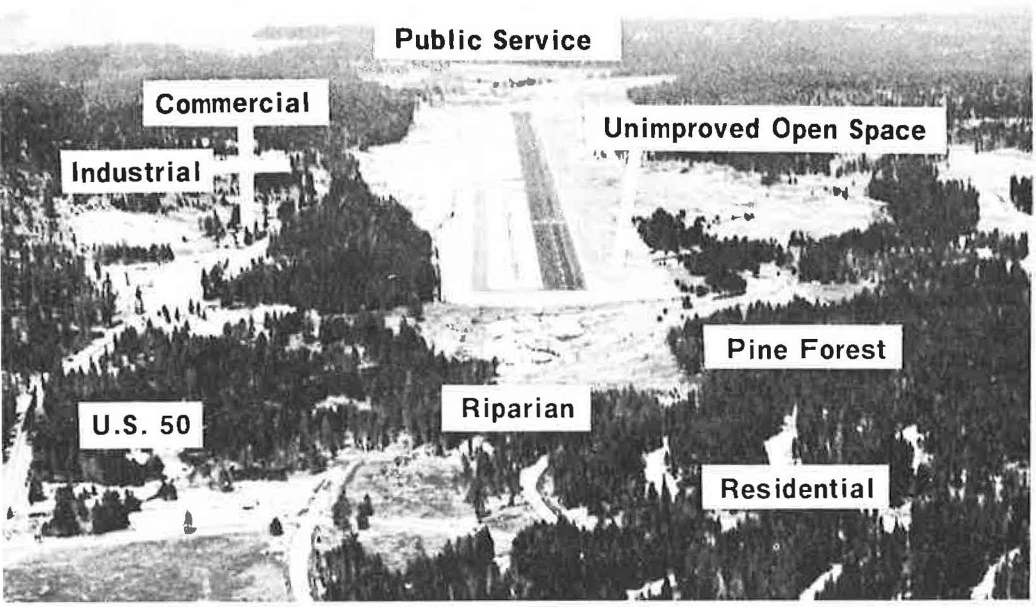
COMPUTER GRAPHICS AND ENVIRONMENTAL MAPPING

Computers are used in studies requiring the storage, manipulation, and array of larg sets of data. Since environmental investigation is increasingly in need of improved data-handling systems, computer technology is developing methods useful to the environmental researcher.

gure 3. Sequential land use.



gure 4. Aerial oblique photograph of Meyers area in 1970 (Department of Public Works photo).



Two methods of computer mapping found to be in use in California are the grid system and the polygon system. With the grid system, a series of rectangular grid cells are overlaid on a base map. Each item of information stored is defined and given a numerical code, which is entered in the grid cell. The drawback of the grid system is the degree of generalization necessary to enter information in the cells. Precise line and point data cannot be transferred.

The second form of computer mapping, which is still in the developmental stage, is known as the polygon or digitizer system. This method allows the operator to trace areas on the source map or aerial photograph with a stylus, which enters the outline and the area—i.e., acres, square miles—of the polygon in the computer memory. The stored information can be retrieved in the form of printout maps of single items, combinations of items, or tabulated numerical data.

An example of a promising digitizer system in the developmental stage is the Wildland Resources Inventory System (WRIS) being developed in two of California's national forests. Information concerning timber types and other related resources such as soils and wildlife is recorded for each township in the forest. The computer can then return a map or tabulated information on one topic forest-wide or several topics in one township or any variation thereof. The resulting computer maps are fractionally coded and can be colored to emphasize special information. Maps from such a polygon or digitizer system are more accurate and more attractive than the product of the grid cell method.

The State of California's Office of Planning and Research is now developing a computer data bank of environmental information to be operated by the Office of Intergovernmental Management. The goal of the data bank is to pool all available natural and man-made environmental information, referenced by USGS 7½-minute quadrangles, in one source. An agency seeking environmental information in a certain area of the state will be able to quickly obtain from the computer all the currently stored data of relevance to environment investigation, thus eliminating much of the hit-and-miss legwork now required to gather information. Such an environmental data bank also allows all state agencies with interest or responsibility in an area to be notified of studies under way in that region, considerably reducing duplication of effort.

The application of computer technology to the problem of highway impact analysis is not always needed, especially where impact areas are small and relatively uncomplicated. Hand mapping remains a useful and efficient alternative for many corridor studies. The main problem facing agencies such as highway departments is knowing what information to gather, how to gather it, and how to interpret and apply that information.

SUMMARY AND CONCLUSIONS

Environmental mapping offers a systematic methodology needed for the interdisciplinary study and reporting of environmental impact. Through geographical identification of the elements of a man-environment ecosystem and the historic and projected changes associated with the system, impact can be identified in both quantitative and qualitative terms. The modeling procedure proposed involves systematic data gathering, synthesis, time interval representations, and graphic display.

A graphic model showing anticipated changes associated with various highway project alternatives, and the no-project alternative, provides opportunity for quantitative consideration of changes in distribution, density, frequency of events, and productivity. It also provides a basis for studying interrelationships and for qualitative judgments leading to beneficial transportation and environmental planning.

The use of maps is especially valuable in this modeling process because maps represent real-world conditions in a manner readily understood by most people. In this way, the necessary community interaction at both the professional and general public levels will produce maximum benefits, in terms of both better plans and better public acceptance.

A number of environmental inventory and mapping studies have been conducted and are presently under way that incorporate various aspects of the techniques and procedures proposed here. A considerable amount of useful geographical data was found to be available for the US-50 corridor study area in an exploratory field research effort. Much of the available data was in need of updating as well as interpretation and synthesis. In corridors where little environmental study has been conducted, more reliance will have to be placed on photographic, interview, and other field data gathering.

Additional application of the proposed methodology is needed for further evaluation and refinement. It also should be tested in environments other than forests.

REFERENCES

1. Bishop, A. B. Socio-Economic and Community Factors in Planning Urban Freeways. Stanford Univ., Rept. EEP-33, Oct. 1969.
2. Lacate, D. S. The Role of Resource Inventories and Landscape Ecology in the Highway Route Selection Process. Rept. to Office of Regional Resources and Development, Cornell Univ., 1970.
3. Bleiker, H., Suhrbier, J. H., and Manheim, M. L. Community Interaction as an Integral Part of the Highway Decision-Making Process. Highway Research Record 356, 1971, pp. 12-25.
4. McHarg, I. L. Design With Nature. Natural History Press, Garden City, N.Y., 1969.

A STUDY OF LAND DEVELOPMENT AND TRAFFIC GENERATION ON CONTROLLED-ACCESS HIGHWAYS IN NORTH CAROLINA

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ABRIDGMENT

A MAJOR problem in planning a controlled-access facility is the task of estimating the volume of traffic that will develop at interchanges. Land values around interchanges increase, and zoning changes to denser classifications cause land developments that were not originally foreseen. Such land developments frequently generate large traffic volumes that tend to overload the interchange. If a reliable method of prediction of land use changes were available, it would then be possible to purchase sufficient land at the outset, where necessary, for a properly designed and stage-constructed interchange. This study is a pilot analysis to investigate if it is possible to make realistic predictions of land development along controlled-access freeways in North Carolina. An attempt has also been made to evaluate the traffic-generating characteristics of these land developments. All controlled-access freeways (a total of 550 miles) in North Carolina have been included in this study.

METHODOLOGY

Base maps for all the routes to be studied were prepared showing land use data up to ½ mile on either side of interchanges. A limited number of origin-and-destination surveys were also made at selected interchanges having differing types of land development. The North Carolina State Highway Commission provided traffic data relative to several complicated interchanges.

The researchers held discussions with the planning officials of the five different cities having controlled-access freeways to aid in making objective judgments concerning which developments were highway-oriented and which were not. The study area was classified into three categories: rural, suburban, and urban. Land development along or near the interchange in a rural area was almost 100 percent highway-oriented. A majority of developments were considered as highway-oriented at suburban interchanges. In urban areas, where the freeway passed through a built-up area, very little development was attributable to the freeway.

FINDINGS

Land Developments by Routes

Generally, it was found that, in a tourist-oriented route similar to Interstate 95, the major type of development was in the form of motels, restaurants, and service stations that would cater to the needs of motorists. On the other hand, along the corridor on Interstate 40 and Interstate 85 connecting the major urban areas in the state, numerous industries and commercial establishments have developed, including a sizable number of service stations, motels, and restaurants.

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Land Developments by Freeway Characteristics

Rural—Approximately 310 miles of rural freeways were studied that included 105 interchanges. It was found that at 35 percent of the interchange quadrants there was some land development, with the remaining 65 percent vacant. The land developments consisted of 117 service stations, 8 motels, 8 truck stops, 9 restaurants, 12 industries, and 14 miscellaneous types, making a ratio of $1\frac{1}{2}$ land developments per interchange or 1.2 developments per quadrant.

Suburban—A total of 171 miles of freeways and 76 interchanges were studied in suburban areas. It was found that some form of land development took place on 70 percent of the interchange quadrants. The developments consisted of 181 service stations, 52 motels, 17 truck terminals, 85 industries, 16 shopping centers, and 49 retail sales outlets, along with other miscellaneous developments, making a ratio of 5.50 developments per interchange or 2.00 developments per developed quadrant.

Urban—Urban interchanges have a much higher density of development. Only 21 percent of the interchange quadrants were vacant, of which approximately half were undevelopable because of the physical characteristics or were state-owned property. The remaining quadrants are either in the process of being developed or being held for development. Of the 71.5 miles and 40 interchanges, there were 70 service stations, 20 motels, 15 truck stops, 61 industries, 6 large shopping centers, 58 retail sales outlets, and 26 office and institutional properties, along with other miscellaneous developments. This made a ratio of 6.5 developments per interchange or 2.1 developments per developed quadrant.

Traffic-Generating Characteristics

The following general conclusions can be made relative to the traffic-generation characteristics:

1. Service stations generate a minimum of 4 to a maximum of 13 trips (one-way) in an average hour leaving the freeway, with 80 to 90 percent of the vehicles returning.
2. Truck stops average 12 to 20 vehicles per hour, including passenger vehicles.
3. Truck terminals, except at certain night hours, average from 5 to 10 trips from the freeway to the terminal.
4. Industrial developments vary from 5 to 50 percent of vehicles at a shift change making use of the Interstate, depending on the location as to whether the major movements are perpendicular to the freeway or make use of the freeway for an urban destination.
5. Motels generate approximately one vehicle moving from the freeway for every 6 rooms in the motel per average daytime hour.
6. Apartment complexes are variable, depending on whether the movement is mainly radial or to the freeway. In one instance during the peak hour there was approximately one vehicle for every 5 housing units making use of the freeway. This was, however, a beltline characteristic.
7. Shopping centers are variable, with up to 50 percent of the traffic coming from the freeway in one case and in others approximately 25 percent of the traffic using the shopping center.
8. Where service roads exist, connecting the freeway interchanges, between one-third and one-half of all of the service-road traffic comes from or goes to the freeway, congesting the intersection.

Predictability of Land Use Changes

Rural—It was found that generally 50 percent of the quadrants in rural areas would remain vacant for a long time and on an average there would be one service station for each remaining quadrant. The question of the exact location of the service station was not pursued to any great extent since it was found that service stations generate very little traffic for the freeway.

Suburban—In suburban areas, the techniques of multiple linear regression were applied to obtain a mathematical expression for estimating land use changes by different type of land use. The predictors were the average daily traffic on the freeway and on the crossroad, population of the nearest city, and distance of the interchange from the city. In order to make the analysis more sensitive, the total sample size for each category of land use was divided into a few subsamples according to the size of the nearest population center.

It was found that generally the location of service stations can be predicted with a high degree of accuracy (maximum $R^2 = 0.99$)[1]. The location of motels can also be predicted with a reasonable degree of accuracy (maximum $R^2 = 0.72$). If realistic judgment decisions may be made regarding availability of land for industrial development, their location can be predicted with a fair amount of accuracy (maximum $R^2 = 0.94$). In most cases, the level of significance was less than 0.25, which signifies that 75 percent of the time the predictions will not be in error. There were not a sufficient number of shopping centers to develop any predictive equations. It was found that shopping centers tend to locate around moderate to large urban areas, depending on the characteristics and availability of land and economic demand.

Urban—The problem of precise predictability of land development in and around urban areas has so many variables that a much more detailed analysis is required to provide specific answers. This study showed, however, that it is possible to make some general conclusions regarding the location of urban activities in and around freeway interchanges. The analysis indicates that some form of land development will take place in all quadrants of interchanges if such land is available for development. The question of exact location of these developments is subject to further research.

Predictability of Specific Types of Developments Near Urban Freeways

The following observations may be made in terms of specific developments near urban freeways.

If land is available at the interchanges and is predominantly residential, the increased value of land near the interchange may give rise to the construction of a large number of townhouses and apartments.

The construction of a freeway of the bypass type, rather than the radial type, with vacant land or with partially built-up land is very susceptible for the development of office and institutional-type activities.

It is realistic to assume that some form of a shopping center will develop on all types of bypasses and beltlines where land is available or where large parcels of land can be put together. Particularly when residential development has taken place beyond the bypass and there is still available land, the chances are high that some form of shopping center will develop between the residential area and the central business area near a major radial interchange with the freeway.

Service roads play a very significant role in the development of industries on freeways. Even if service roads are not available there is an apparent trend to build private roads away from the interchange connecting other radial roads, with the vacant land being developed into prestige location industrial parks. These industrial parks make for major generators at the intersection of the radial routes and the freeway interchange.

CONCLUSIONS

In this pilot study, an analysis was made of changes in land developments that have taken place on controlled-access freeways in North Carolina. It was found that developments in rural areas were predominantly service stations and so scattered that there was no predictability as to the location. In suburban areas developments were denser and location of service stations, motels, and industries could be reasonably predicted.

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[1] The value of R^2 denotes the percentage variation of the dependent variable that can be explained by its relationship with the independent variables.

In urban areas, developments could be qualitatively predicted, although the factors involved were so numerous as to prohibit the use of statistical analysis on the moderate number of samples.

Major traffic generators for the freeway were the industrial plants and shopping centers, while the other developments (motels, restaurants, service stations, and apartment complexes) have very little effect on the operation of the interchange if these are located by themselves.

RESOURCE ALLOCATION AND THE SYSTEM PLANNING PROCESS

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This paper addresses the question of how a state highway or transportation agency divides or allocates resources among a number of regional districts. The discussion concerns itself with how various allocation methods affect the size and location of proposed projects and how allocation affects the disposition of regional agency personnel to interact with communities and respond to their needs. Beginning with a range of idealized allocation methods intended to expose issues in allocation, the paper shows how such simple schemes illuminate the description of an actual state allocation method—that used in California for allocation of the California State Highway Fund. The paper then develops some requirements on allocation methods that derive from the need to make planning more responsive to a range of community and environmental factors. Finally the paper analyzes the incentives that operate on planners when allocation is based on programs proposed by the regions to the state for implementation and when it is based on non-program factors.

•THE highway system planning process at state and local levels has experienced considerable change over the past 15 years or so as tools and techniques for planning have been developed and improved. As America moves into a complex post-industrial age, it is evident that the present process, based in the traditions of the late 1950's and 1960's, will have to undergo as rapid and profound a change in the next few years as the whole 15 years before if it is to respond to this complexity and to the increasing demands of citizens for involvement in decision-making. An essential component of this response should be a thorough analysis of the components of a system planning process and of the role each can play in determining the outputs and behavior of a system planning process. Some process components, such as the institutional structure and the funding sources, are recognized by all. This paper addresses the implications for designing a planning process responsive to community and environmental concerns of a less obvious component: the method used by the process for allocating state-level funds to regional agencies for use in transportation planning and implementation.

This research is part of a larger effort devoted to the problems of incorporating community and environmental factors into statewide transportation planning (1, 2). The primary concern of this paper is to investigate the important implications of allocation for the process outputs and behavior, taking the total amount of resources to be allocated as fixed. The major emphasis will be the influence that allocation has (a) on project location and (b) on a planning agency's incentive to interact with and respond to community concerns.

To facilitate presentation of the issues in allocation, the discussion will begin with a presentation of a variety of conceptually "pure" allocation schemes, where any actual allocation scheme can be viewed as a combination of these pure processes. Reviewing possible alternative allocation schemes leads naturally then to a typology of allocation schemes. The allocation process used for a particular state's highway fund will then

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be described and its relationship to the alternatives defined. The description will also identify some significant problems with the present allocation process.

The final sections present some important requirements for allocation that are implied if the system planning process is to respond to future uncertainties, especially the uncertainty of community acceptance.

ALTERNATIVE MODELS FOR THE ALLOCATION PROCESS

To familiarize the reader with the issues raised by various allocation methods, it is appropriate to present six rather extreme, simplified allocation schemes that are conceptually pure and whose biases can be easily understood. These alternative schemes can be combined to yield most of the existing allocation methods for federal and state programs. The six allocation schemes are

1. Economic efficiency,
2. Benefit/cost ratios,
3. Consistency of resources and statewide level of service,
4. Equity,
5. Individual project, and
6. Political allocation.

The first five are based on analysis techniques applied by the state agency either to projects proposed by regional agencies or to socioeconomic data. They view allocation as a technical analysis problem. The sixth scheme is radically different in that it views allocation as a political process, as a mechanism for negotiation of the inevitable conflicts of interest that always occur between state and regional levels. It recognizes explicitly the bargaining or conflict that would occur in the other five methods but is obscured by their analytical definitions.

We believe that a political allocation process is much more appropriate to a system planning process designed to incorporate community and environmental factors than an allocation based solely on technical analysis.

The following sections describe the six models in detail.

ALLOCATION BASED ON ECONOMIC EFFICIENCY

A very attractive conceptual method for performing allocation is based on the concept of economic efficiency (Fig. 1). That is, a state highway agency may choose to maximize aggregate net benefits to the state for a given amount of resources, without regard for their distribution among regions. For the present, project size or scale (2, 4, 6 lanes) can be assumed to change continuously. The conditions of economic efficiency require in theory that the marginal benefit/cost ratios for all projects funded be equal. In other words, projects are designed so that the additional increments in benefits for an extra dollar of investment for any one project are equal for all projects. If project benefits go up with project cost (or size) in dollars (Fig. 2), this means that the slope of the benefit versus cost curve will be the same for all funded projects in an economic efficiency allocation. Note that the ratio of total project costs to total benefits may not be the same for all funded projects. Given total resources and a number of candidate projects, each with a benefit versus cost curve, the marginal conditions above establish which locations receive projects and the optimal or best project size at each location. In general, the scale of each project will vary with the aggregate resources available.

Because of this, efficiency allocation requires that the state send each region an allocation guideline or approximate allocation. The state also specifies the variables that make up the benefits and costs to be considered in evaluating projects. Benefits would include time savings, accident reductions, etc.; costs would include construction, maintenance, impact amelioration measures, and so on. The regions then calculate their facility locations and sizes to arrive at candidate projects and a candidate program for review by the state. Because the marginal benefits from candidate projects will tend to diminish with increasing project size, the regions each try to allocate funds to projects so as to preserve the highest common marginal benefits possible and still spend the amount of their guidelines. Note that benefits and costs of projects will also account for those derived from project interdependence or network effects.

Each region then sends the state its candidate programs, consisting of a list of candidate projects, and the region's marginal benefit/cost ratio. In general, the marginal ratios calculated in each region on the basis of the allocation guidelines will not be the same since each region has different investment opportunities. The state then changes the guidelines to move funds from those regions with lower marginal benefit/cost ratios to those with higher ratios and issues new guidelines to the regions. New candidate programs are then developed by each region in response to these new adjusted guidelines, and project sizes and locations will change in some regions. New regional candidate programs are then submitted to the state, marginal benefit/cost ratios are again checked for consistency, and the process is repeated until the ratios are equal for all regions. This method of allocation is discussed more fully as the Lange-Lerner approach to investment planning by Marglin (3).

The equilibrium marginal benefit/cost ratio will probably be greater than 1, indicating that scarce resources for transportation prevent building projects out to the optimal marginal benefit/cost ratio of 1. In other words, all projects are profitable in a benefit/cost sense, and more resources could be devoted to transportation.

The essential point about allocation based on economic efficiency is that the project locations and sizes prepared by the regions are a function of the size of their allocations.

An important implication of an efficiency allocation scheme is that the candidate projects used for the allocation do not, in general, provide a uniform level of service distribution (speed distribution) across the state. Due to their greater valuation of time savings, the relatively richer regions receive higher levels of service than do poorer regions. This is because a higher level of service must be reached before the marginal benefits of additional project investment are the same as for lower income areas. Denser regions tend to have lower travel speeds because trips there are short and building costs high. Thus, efficiency allocation provides for aggregate efficiency but essentially ignores issues of incidence of benefits or equity.

ALLOCATION BASED ON BENEFIT/COST RATIOS

An economic efficiency allocation scheme assumes that project size and location are variable. In practice, this freedom is usually not available due to restricted project locations, size, or design standards. It is useful then to sketch out a second allocation scheme that generates the economically most efficient allocation given that size and location of candidate projects are fixed for each region. The allocation is based on fixed location project benefit/cost ratios. Figure 3 shows how this allocation scheme would function.

Each region develops benefits and costs for a large number of specific projects it would like to build. These regional project benefits and costs depend to some degree on project interdependence, but within a range of allocations the benefits and costs of projects are taken as independent of each other. In the case of transportation projects where network effects can be important, this assumption sometimes may be extremely difficult to justify.

Each region ranks its list of candidate projects by aggregate benefit/cost ratio, and the state combines these regional project lists together into a master state project list containing all projects from all regions ranked by benefit/cost ratio. This list is then funded as far down as resources permit, each region receiving as its allocation the costs of its projects that appear on the funded list. Each region's funded projects constitute its candidate program.

An important assumption here is that there are a great many projects in the funded list, with no one project being a significant percentage of the budget. Thus, project indivisibilities do not prevent allocation of the whole budget. In the ideal case where every region has many projects, and where benefit/cost ratios are distributed randomly over the state, the last funded project in each region's candidate program would have roughly the same benefit/cost ratio. This last project can be viewed as the marginal regional investment, and the method ensures, under ideal conditions, that the marginal

Figure 1. Allocation based on economic efficiency.

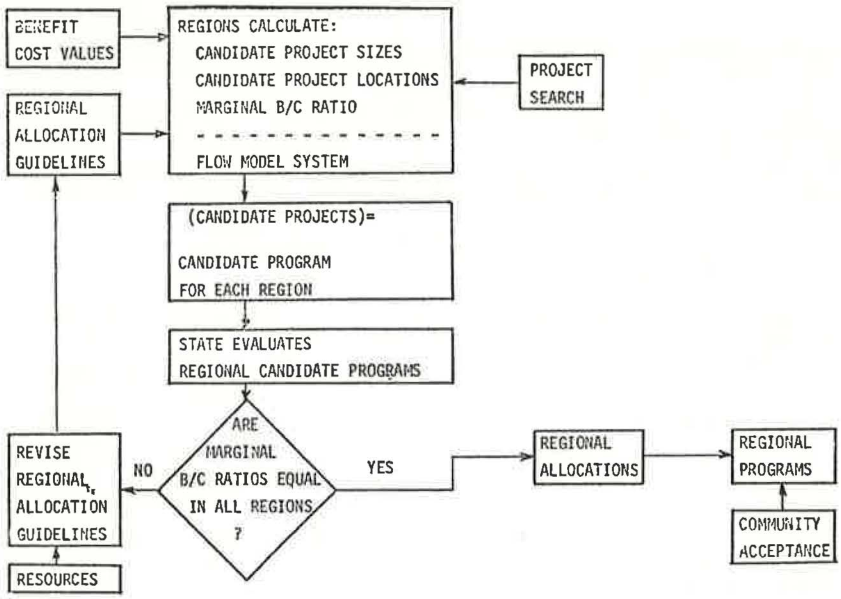


Figure 2. Project benefit versus cost curve.

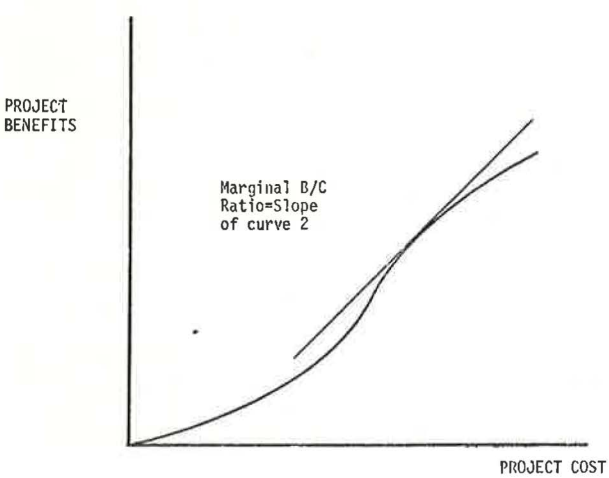
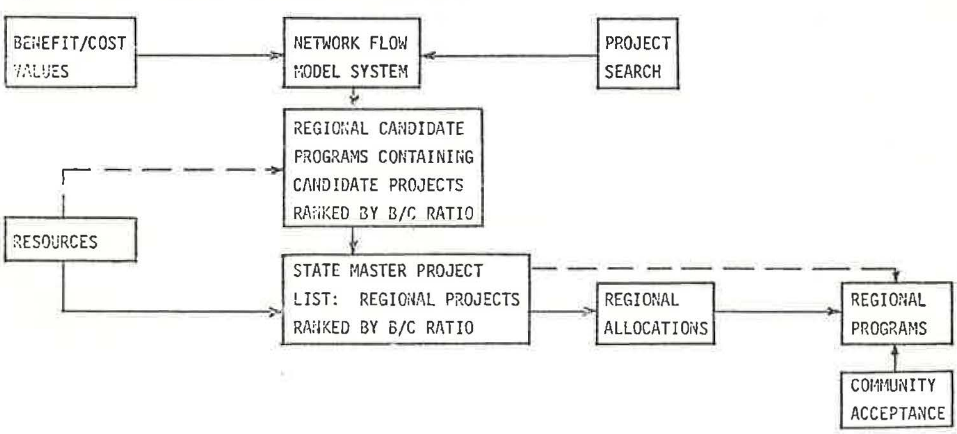


Figure 3. Allocation based on benefit/cost ratios.



benefit/cost ratio in each region will be roughly the same. In general, however, these conditions would not be likely to hold.

Benefit/cost allocation is a cruder measure than true efficiency allocation, which requires the marginal benefit/cost ratio of each project to be equal. Benefit/cost ratio allocation is an approximation to true economic allocation where project size and location are given and shares most of the strengths and weaknesses of efficiency allocation.

ALLOCATION BASED ON CONSISTENCY OF RESOURCES AND STATEWIDE LEVEL OF SERVICE

The third allocation scheme is based on maintaining a given transportation level of service (LOS) distribution over the state, which is similar to many state allocation schemes. Such a distribution could be specified as required speeds on the links of the master plan. Or it could be specified as an inter-facility spacing requirement, perhaps dependent on trip end density. The LOS distribution may or may not be similar to the one that falls out of an efficiency or benefit/cost ratio allocation. Figure 4 shows the allocation process based on a LOS distribution assumption.

To predict the facilities needed to meet the LOS in each region, a sophisticated traffic flow prediction model is required. The model must be able to handle congestion and express travel demand as a function of LOS because, if the costs of project construction projected by the model are higher than resources available, the calculation must be rerun with lower levels of service (LOSL) until the costs of service can be met. It is important to note that adjusting the LOS down to LOSL to reflect scarce resources yields a different list of candidate projects than merely truncating a list derived for higher levels of service (LOSH) to reflect a binding resource constraint. The shift in project list is similar to what happened in economic efficiency allocation when different candidate programs were developed for different allocation guidelines. Both project location and size could change. In this case, the LOSL calculation might result in a list of projects of financial magnitude (arbitrary units) 10, 8, 7, 6, 6, 4. The LOSH calculation might generate a project list of 12, 11, 10, 8, 8, 7, 6, which would be truncated by the resources constraint down to 12, 11, 10, 8. The truncated list can be met by existing resources, but its individual projects are fewer, larger, and perhaps in different places than those in the more correct LOSL list. California's State Highway Fund allocation process contains a similar truncation.

After a candidate project list reflecting consistent LOS and resources has been derived, the allocation then pays each region the cost of its projects that appear on this list, and the projects become the region's candidate program.

Consistency allocation may not give deterministic allocations if demand is highly responsive to supply. Due to induced travel demand, there may be several funding levels that result in roughly the same LOS distribution over space. Also, there is no inherent check on the desirability of individual projects as there is in the efficiency allocation and benefit/cost ratio allocation.

EQUITY ALLOCATION

The fourth major criterion that might be chosen for allocation is one based on equity considerations. There are several possible definitions of equity:

1. Equal LOS distribution in all regions (with an urban-rural subdivision);
2. Equal expenditure per capita, per mile of road, per mile of travel, per political district, etc.;
3. Regional expenditures equal to taxes paid; or
4. A special case of the previous alternative, LOS/resource consistency.

The second scheme suggests an allocation process based on formulas using socioeconomic data (Fig. 5). Income transfers may occur under this scheme. Indeed, the formula might even overcompensate poorer regions to make up for previous deprivation. The third scheme would prevent any income transfers between regions and, in the case of gas tax funding, would discriminate heavily against rural areas. This is especially true if maintenance funds are handled through allocation from the state level.

The results of an allocation based solely on a definition of equity will probably be significantly different from either of the procedures based on economic efficiency. The latter are likely to emphasize investment in growth areas (the urban fringe) at the expense of rural and central urban areas, whereas the former is likely to spread resources more evenly across urban, suburban, and rural areas. Distributional objectives almost always come at the cost of a certain amount of aggregate economic efficiency.

INDIVIDUAL PROJECT ALLOCATION

One of the most significant problems with statewide allocation lies in the area of community acceptance of the projects used as candidates in allocation calculations. One obvious way to avoid the problem is to fund local projects directly from the state level. Local agencies would negotiate projects knowing that state money would become available at some point if agreement could be reached in a proper manner among local groups and this fact could be demonstrated to the state (Fig. 6).

Individual project allocation takes the view that people's needs are what they want and can agree on. The advantage of this is that it removes a lot of the pressure on planners to build something. The disadvantage is that, even with regional allocation ceilings, areas with little opposition will still get most of the money actually allocated. There is little incentive for planners to seek agreement in regions containing conflict.

POLITICAL ALLOCATION

All of the allocation methods presented above deal with abstract characteristics of potential projects or their environment. As shown by flow charts, all the processes have the atmosphere of detached analysis about them. They imply that allocation occurring at the state level (before actual programming and implementation occur) is not a place for political decisions over what should be built.

But the choice of allocation process is itself a political decision, for different allocation methods will bias actual project decisions in different directions. This is evident from the previous sections. There is no objectively "right" way to perform allocation; it is basically a political process.

It is useful, then, to sketch out an allocation scheme that explicitly views the allocation process as a political process aimed at working out conflicts of interest between state and regional levels. Such a political allocation requires that there be a state-level body to review regional proposals that is representative of and responsive to statewide interests. This review body bargains politically with the regional agencies. The bargaining could restrict itself to decisions about parameter values to be used in the various models described in the foregoing sections, but this would limit discussion to those few project attributes that are convenient for analytical modeling. By its nature, political allocation will want to deal with the political issues implied by transportation, and today these often revolve around the community and environmental factors affected by transportation. The state also wants to concern itself with the <u>differential</u> impacts of proposed projects and programs, with who gains and who loses when particular allocations are made. Therefore, the bargaining in political allocation must proceed directly from specific project proposals.

Political allocation, then, is based on a comprehensive analysis of what the regions receiving allocation intend to do with the money (Fig. 7). The state requests candidate programs from the region, providing allocation guidelines for cost and for the particular type of transportation the state would like to see emphasized. The regions respond with candidate programs designed to meet state guidelines but also to further what the regions see as their regional interests. Naturally, there is potential statewide regional conflict here, and bargaining over the candidate programs will generally occur. Candidate programs may be returned to the regions as unacceptable or may be renegotiated by them if they are likely to receive low allocations. The regions can also pressure the state to accept their programs.

The bargaining over candidates is inseparable from the actual allocation decisions to be reached at the state level by the responsive and representative decision body

Figure 4. Allocation based on resource and LOS consistency.

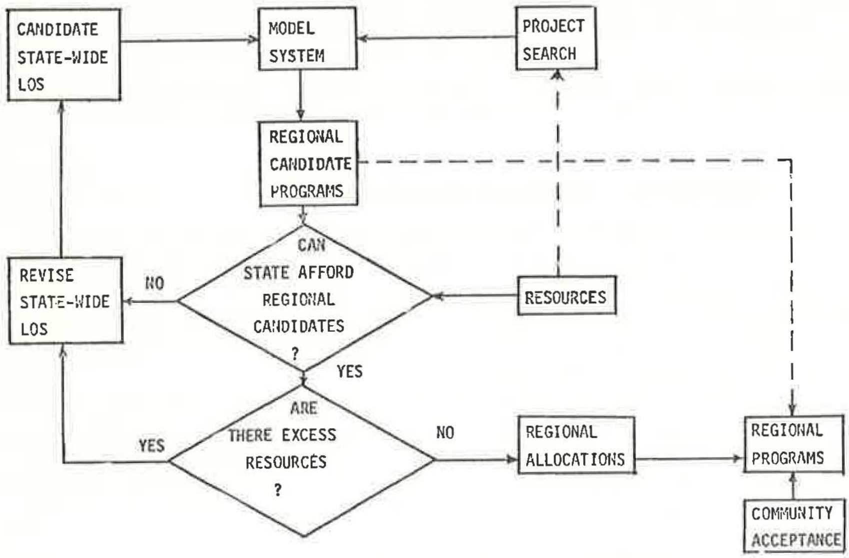


Figure 5. Socioeconomic allocation.

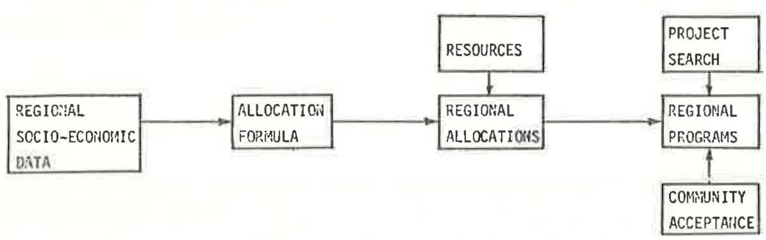
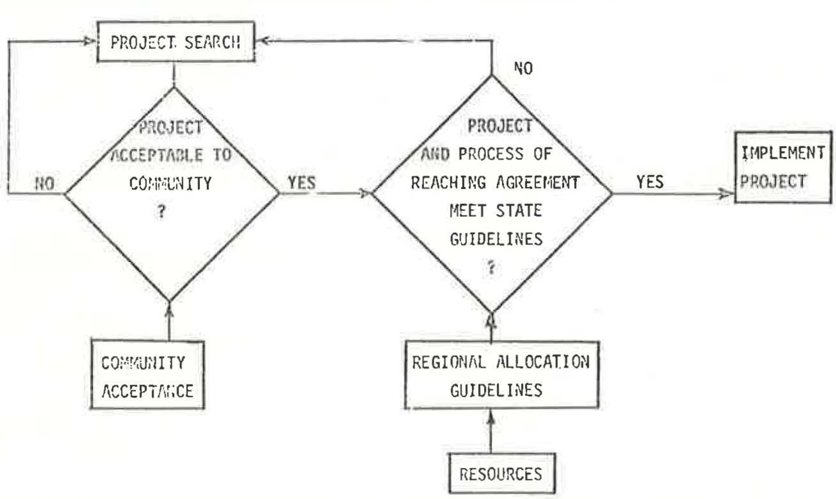


Figure 6. Individual project allocation.



mentioned earlier. Aspects of the candidate program are aggregated and compared to expose the differential aspects of proposed projects. The state uses a variety of analysis techniques, perhaps those in all of the allocation processes described above, to arrive at decisions about candidate programs and allocations.

Eventually the political process arrives at a negotiated settlement in which the state agrees to allocate given moneys for given candidate programs and the regions agree to build the candidate programs.

The political allocation process represents a mechanism for inter-level bargaining between state and regional levels. Perhaps such behavior would occur spontaneously in the other candidate program-based processes mentioned. But in the political allocation process, it is explicitly recognized and viewed as a possible benefit.

Because it is not restricted to narrow methods of analysis, political allocation is capable of considering a much wider range of community and environmental factors than the other allocation models mentioned. As a result, we believe that the political allocation model is most appropriate for system planning processes that seek to incorporate community and environmental factors in their planning.

A TYPOLOGY FOR ALTERNATIVE ALLOCATION PROCESSES

The foregoing alternative allocation schemes can be ordered into a typology that is useful for comparative purposes. The basic subdivision depends on whether or not an allocation scheme involves consideration by the state of candidate programs submitted by the regions in response to state guidelines. Within candidate program-based allocations, processes may be further categorized depending on how the resource constraints at the state level are applied. In some cases the regions are required to respect the resources constraint in developing their candidate programs. In some cases, candidate programs are not constrained by resources; allocation may be performed on the unabridged candidate programs, following which the regions truncate their programs to respect the limits of their allocations. This is what is done in allocation of one specific state highway fund, the California Highway Fund. Finally, the state may apply the resource constraint to a master list of projects from all regions ranked by desirability (benefit/cost allocation).

Alternatively, allocation can be based on non-program factors such as population, income, miles of road, miles of travel (socioeconomic allocation). The typology is given in Figure 8, with the example allocation methods corresponding to each subdivision given in parentheses.

ALLOCATION OF THE CALIFORNIA STATE HIGHWAY FUND

The major purpose for developing the six allocation schemes in the previous sections is to facilitate description of existing state transportation allocation schemes. A good example of such a scheme is the allocation of the California State Highway Fund, the primary source of funds for the California state highway system.

The choice of California does not imply special condemnation or concern. Rather the California allocation scheme is chosen because it is believed to be exemplary of a great many allocation methods used by state highway agencies. In fact, the California Division of Highways has a reputation as one of the most professional and innovative highway departments in the United States. The Division is already becoming aware of some of the implications of allocation for its decision-making process (4).

California's State Highway Fund is allocated to regional districts for construction and maintenance of the California state highway system (Fig. 9). California's highway planning objective ostensibly is to maintain a constant distribution of LOS on the system in urban and in rural areas. Thus, allocation contains elements of an "equity" allocation based on constant LOS. We will see that the allocation also contains elements of benefit/cost allocation.

Allocation of the Fund is primarily a function of the resources the districts say they need to remedy "deficiencies" in the system—i.e., parts of the system presently offering LOS below statewide standards. The Fund is subject to a legislatively defined north-south split; the northern part of the state presently gets 40 percent of the Fund,

Figure 7. Political allocation.

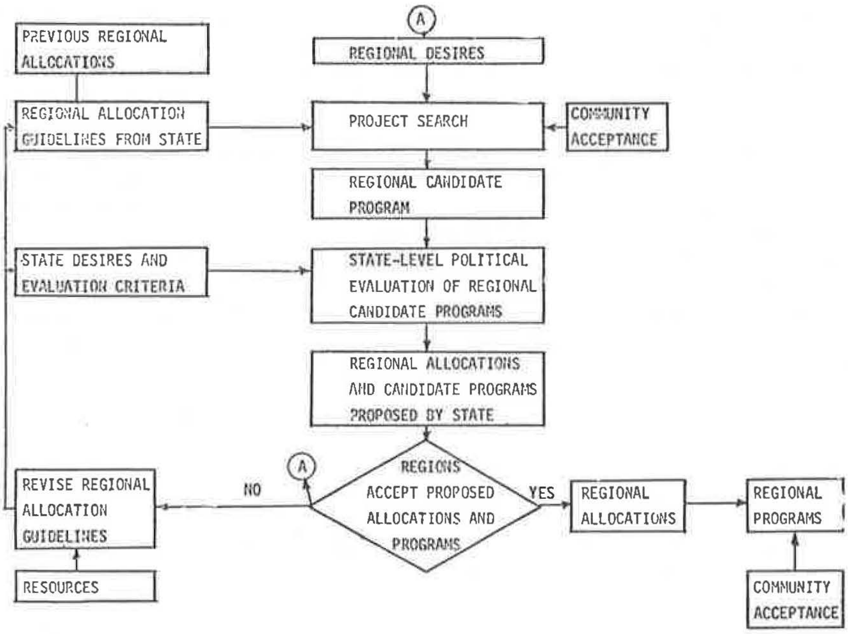


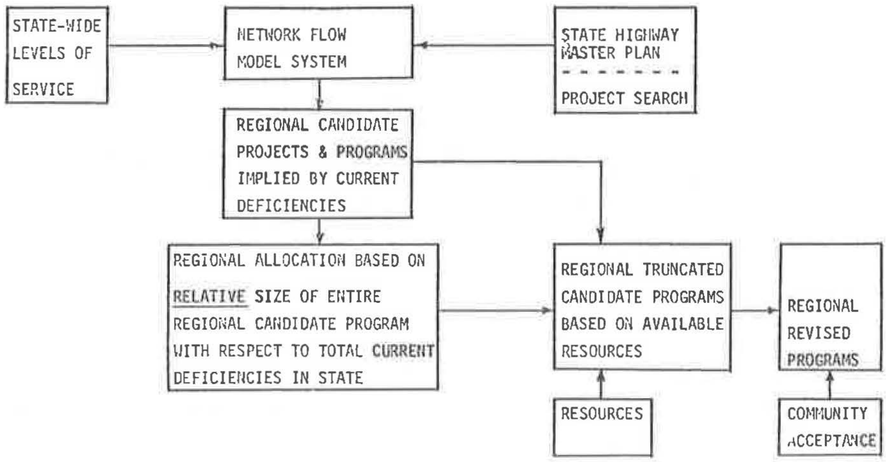
Figure 8. Typology of allocation methods.

A. Program-based allocation with resource constraint before allocation
   1. Constraint imposed by allocation guidelines (economic efficiency, single projects, political allocations)
   2. Constraint imposed by iteration and adjustment of quality guidelines (LOS/resource consistency allocation)
   3. Constraint applied to state master list (benefit/cost allocation)

B. Program-based allocation with resource constraint after allocation (allocation of California Highway Fund)

C. Non-program-based allocation (socioeconomic allocation)

Figure 9. Allocation of California State Highway Fund.



the southern part 60 percent. Within each part, allocation of 70 percent of the money must be based on "needs"; the allocation process described here is the "needs" allocation. These deficiencies are determined by the state transportation network flow model but, although existing traffic generators are used, no link capacities are used, only travel speeds, in specifying the network. And links occurring in the freeway and expressway system master plan are included in the assigned network whether or not a road presently exists in the alignment. Thus the model predicts the travel that would occur on the state network if travelers experienced no congestion and could travel at statewide LOS levels. Naturally, the flow model delivers many link flows that, were they to use existing facilities, would experience service below statewide LOS. Such links are called deficiencies.

Once the locations of present deficiencies are established, the network flow model is then used to predict how big the improved facilities must be to remain uncongested for 20 years. As deficiencies, the districts report the cost of these improved facilities. Allocation is then based on the relative size of the entire reported deficiency lists from the districts. After allocation, the districts rank their separate deficiencies by indexes similar to benefit/cost ratios and fund their lists as far down as possible.

One notes immediately that the resource constraint is applied only after the actual allocations have been made. The truncation of deficiency lists means that the projects that actually are funded are larger and in different places than those that would be built by an allocation based solely on a resource/LOS consistency allocation scheme.

One can also view the California State Highway Fund allocation process as related to the benefit/cost allocation of the previous section. The deficiency lists submitted to the state are similar to the lists of high benefit/cost ratio projects they might submit for an allocation based on benefit/cost ratios. Truncating the district deficiency lists is then similar to the truncation of the master project list called for in benefit/cost allocation. As noted in a previous section, however, because of demand elasticity and network effects, project benefits and costs depend on the assumed size of the system. Because the system size assumed in the California allocation is somewhat large, the benefits and costs assumed for projects are probably unrealistic. Thus, even if California's process is viewed as an approximation to a benefit/cost allocation, its output is projects that probably are both too few and too large for the most effective use of highway funds.

The use of the high LOS values and uncapacitated flow model is the same thing as assuming an ultimate system large enough and growing fast enough to operate indefinitely without congestion. In other words, the allocation method assumes that, although present revenues fail to cover reported deficiencies (i.e., districts must truncate their reported deficiencies), in the future they will. But this is very unlikely since at the present time projected deficiencies diverge from expected revenue as target years further in the future are considered (5).

There are other problems with an allocation method such as California's. It is clear, for instance, that imposition of the resource constraint after allocation encourages districts to inflate their deficiency lists wherever possible in efforts to gain a larger allocation relative to other districts. Such maneuvering will "cancel out" of the allocation calculation only if every district's deficiencies are inflated by the same percentage.

ALLOCATION AND THE FUTURE

So far the role of time has been ignored in the discussion of allocation. It has been assumed implicitly that implementation of projects occurred immediately after allocation and thus that the benefits, costs, and LOS changes of that implementation occurred soon after allocation. But the planning and construction of major public facilities is time-consuming; the benefits and costs of these activities in fact occur over decades.

A central problem for allocation is dealing with this future. Allocation must decide which future project costs and benefits to include in its calculations. Where it is based on candidate programs, it must also decide which future projects to include.

It was noted earlier that the future benefits and costs of present and future projects may not be independent of each other. The benefits and costs of project A may depend on whether project B is built. More generally, project benefits and costs depend on the size system assumed. If a large system is assumed, the same project may have significantly different benefits and costs than it would in a smaller system. This is especially true if demand (including land use shifts) is viewed as a function of facility supply. A prediction for future system size, however, depends to some degree on assumed future funding levels. Furthermore, because future projects are planned for specific regions, their benefits and costs depend on assuming the level of funding available to that region. This is tantamount to assuming the allocation itself. Thus there is an element of circular logic involved in allocations based on candidate programs.

Similar circularity also occurs in non-program-based allocation based on socioeconomic data. Should present or future data be used? If future data are used, these data could depend on the magnitude and distribution of public services, including transportation. Political allocation, because it must use analysis methods implied by other allocation processes, will also contain circularity.

Allocation calculations, then, must always assume a future and to some extent prejudge their own conclusions. This circularity is, of course, less serious the more society's growth and change can be taken as independent of the public service (in this case transportation) for which allocation is being performed.

In analyzing an allocation process, the planner should always ask what sort of future is being assumed. Is the future reasonable? It was noted earlier that California's State Highway Fund allocation assumes a very large future highway system.

If the allocation is based on candidate programs, one must also ask which projects are allowed in the candidate. Strictly speaking, allocation should consider only candidate programs capable of implementation in the next allocation period. But often they contain more.

The California State Highway Fund allocation is based on the total list of present deficiencies as calculated by the network flow model. This list presently contains so many projects that all present deficiencies could only be funded over several allocation periods. The assumption is that all the candidate projects will eventually be built. This is just another way of prejudging the future.

Basing allocation on near-term projects is complicated by the long project lead times characteristic of transportation. Candidate projects can only be built in the next period if planning activities have been funded in previous periods. And if allocation is to be periodic, allocation for the next period must include funds for the planning of projects in periods beyond the next one.

The obvious way to handle this problem is to view the planning phase of future facility development as a project in itself, which has some sort of payoff in benefit/cost or LOS in later allocation periods.

The notion of planning as a "project" in allocation becomes stronger if the planning activity does not presuppose a given facility but is a more general search for a transportation solution to a problem. A corridor study, for example, might not lead to any one particular facility, and thus the study's benefits are more difficult to see than those of that facility. But by aiding on some facility, the study makes a contribution to benefits or LOS in generalized terms.

In short, the logical reconciliation of candidate program-based allocation and long project lead times involves subdividing project development into phases that fit into single allocation periods.

FUTURE UNCERTAINTY AND COMMUNITY ACCEPTANCE

Allocation schemes should approach prediction of the future with caution precisely because it is so uncertain. There are large uncertainties in prediction of project benefits and costs and in forecasts of resources available. A particularly difficult form of uncertainty for allocation is community acceptance.

For consistency, an allocation based on candidate programs should be based on candidate projects acceptable to their communities. Judging community acceptance is difficult if not impossible if allocation is based on projects far in the future.

In the case of California's allocation, it is quite unlikely that some of the projects in the candidate program will ever be built. This is because, as noted in the previous section, many of the projects used in allocation could not be implemented for several allocation periods due to resource constraints, and many probably bear no relationship to what will eventually be acceptable to communities.

Again, long-term project lead times complicate the task of basing allocation on more near-term projects that are more immediate to communities. But if project development is subdivided into project development phases, an allocation scheme more visible to communities might be achieved. Candidate programs for the next allocation period would consist of project development phases proposed for the next allocation period whose acceptance potential was high. Acceptance can best be judged by the success of planning in the current allocation period. For instance, if district programs under the present allocation contain corridor location and corridor study project development phases and if agreement with communities is reached on planning through corridor study, then the district may legitimately include the cost of the route location phase in its next candidate program for allocation. Similarly, if one allocation period achieves agreement on route location, the candidate program for the next period may contain the costs of right-of-way acquisition and even implementation. If programming uncertainties made it desirable to pursue two corridor studies, even though only one would eventually be carried to corridor agreement, the candidate program should contain both as valid expenditures.

ALLOCATION AND PLANNERS' OBJECTIVES

A major consideration in allocation process design is the effect a given allocation method will have on the day-to-day workings of regional agencies spending allocation resources in the field. In this regard, the major issue is whether or not allocation is based on a candidate program.

If allocation is based on a candidate program, regional agency personnel will tend to generate as large a candidate program as they can justify. But in order to remain consistent with their allocation, they are then under pressure actually to build the candidate projects or similar ones during the allocation period. Such pressure will be more intense the less flexibility there is to substitute projects for candidates, the further into the future the candidate program extends, and the less chance the agency has to test community acceptance in developing the candidate program. Even if a short-term candidate program is chosen and wide substitution flexibility allowed, the incentive is to build <u>something</u>. Regional agencies may pursue extensive community interaction activities, but such activities will not shift incentives if implementation consumes 80 to 90 percent of the budget. Planners operating under a candidate project-based allocation tend to be impatient with community resistance however altruistic their intentions might otherwise be. They become most impatient when communities simply obstruct all action because of disagreement on the very goal of implementing <u>something</u>. Such resistance is very different from opposition that planners can "buy off" through agreement to compensation programs or a more expensive project design.

If allocation is divorced from a candidate program, promotion and prestige at the regional level are not so closely linked to implementation. In the case of socioeconomic allocation, the regions merely have to spend their allocated resources <u>somehow</u>. Naturally, such an allocation results in less construction project per dollar of allocation and more process (e.g., community interaction, liaison). Allocation could result in a lot of planning activities but relatively fewer implementations. But those implementations that were agreed to would probably respect community needs in a more sensitive manner. Planners operating under non-candidate program-based allocation will be better able to handle community resistance to projects because the alternative of doing nothing does not threaten them.

If it can avoid or placate community resistance, a candidate project-based allocation will tend to deliver more system per dollar than non-candidate project-based allocation. It will also emphasize the system aspects of transportation more. Candidate program-based allocation results in an explicit "product" for resources committed by the state to transportation. This product is a given LOS distribution or a given benefit/cost ratio at the margin. In allocation not based on candidate programs, public satisfaction with the process becomes part of the product. Process becomes itself an end, the process of carefully seeking out community transportation needs and satisfying them where agreement can be obtained. Because such agreement is most likely to be effective at local levels, non-candidate program-based allocation tends to de-emphasize the system aspects of transportation implementation.

Allocation, then, affects the bias of the system planning process toward a "product" or "process" orientation, depending on whether it is based on a candidate program or not. In the long run, this influence may be the most important issue in the choice of an allocation mechanism.

SUMMARY AND CONCLUSIONS

The allocation method used by a state highway agency periodically to divide its funds among state regions is a powerful determinant of the outputs and behavior of the planning process pursued by the agency. The allocation method heavily influences the location and size of projects that become candidates for planning and construction. It is also one of the places where the process must make assumptions about the future size of the system it will build and about the future acceptability of that system to communities.

Allocation schemes based solely on economic and technical analysis tend to obscure the fact that allocation is basically a political process and should provide an opportunity for the state and its region to negotiate their differences. An allocation that recognizes this is desirable if the system planning process as a whole is to incorporate community and environmental factors in planning.

The analysis of the allocation method used in allocation of the California State Highway Fund indicates that present allocation processes may be making uneconomic allocations and adopting assumptions about the future that are no longer very sound. It is time to review these process designs and adapt them to present demands and present visions of the future.

In doing this the problem of future uncertainty and the need to involve communities more deeply in transportation system planning must be emphasized. If allocation is based on candidate programs, these factors militate for an allocation method based primarily on candidate projects implementable in the next allocation period, for such an allocation makes the least restrictive assumptions on the future. The conflict between this objective and the long project lead times characteristic of transportation can only be resolved through the subdivision of project development into phases whose duration matches the allocation period of the process. Finally, increased emphasis on community interaction may require allocation methods based less on proposed regional candidate programs and more on socioeconomic data.

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REFERENCES

1. Manheim, M., et al. Community Values in Highway Location and Design: A Procedural Guide. M.I.T., Cambridge, USL Rept. 71-4, Sept. 1971.
2. Pecknold, W. M., et al. Transportation System Planning and Community and Environmental Values. M.I.T., Cambridge, USL Rept. 72-3, June 1972.

3. Marglin, S. Approaches to Dynamic Investment Planning. North-Holland Pub. Co., Amsterdam, 1963.
4. California Department of Public Works. Allocation of Highway User Taxes. Report for the Resource Allocation Committee, Dec. 1971.
5. Spiraling Costs: A Report on the Causes and Effects of Increasing Highway Project Costs and on Recommended Courses for Action. California Division of Highways, Aug. 1970.
6. Mead, K. C., et al. Basic Issues in Incorporating Community and Environmental Factors in the Transport System Planning Process. Presented at Annual Meeting of the Transportation Research Forum, Oct. 1971.
7. Koppelman, F. S. A Model for Highway Needs Evaluation. Highway Research Record 314, 1970, pp. 123-134.
8. Mead, K. C. An Improved System Planning Process for California. Department of Civil Engineering, M.I.T., Cambridge, PhD thesis, Aug. 1972.
9. Pecknold, W. M. The Evolution of Transportation Systems: An Analysis of Time Staged Investment Strategies Under Uncertainty. Department of Civil Engineering, M.I.T., Cambridge, PhD thesis, 1970.

BALANCING PROJECT COSTS AND REVENUE TARGETS

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The search for ways to stabilize the highway financial planning process is meeting with only limited success. Some of the reasons for this are national inflation, environmental complaints, and a strong desire for public involvement in the highway program. One approach being tried by the California Department of Public Works is to deal with change as inevitable and then to look for faster methods of responding to change. A technique has been developed, using a computer with video display terminals, for balancing project costs and revenue targets. The remote terminals, linked by telephone lines to a central computer, enable engineers to retrieve construction and right-of-way estimates from a data bank. Each project cost estimate can be displayed on a video screen, apportioned among fiscal years of expenditure, advanced or delayed to different fiscal years, escalated or de-escalated, and resummarized for balancing against revenue targets. This technique greatly reduces the time-consuming work of balancing and refining a long-range highway financial plan under pressure of frequent change.

•HIGHWAY planning is not the same animal it was 10 years ago. The financial end of highway planning has been especially vulnerable to the changes taking place in our society.

For instance, the combined highway cost escalation rate in California is about 10 percent compounded annually. The combined rate refers to inflated construction and right-of-way costs, plus the effect of improved safety, environmental, and service standards. This means that a $5 million project being planned in 1970 becomes a $15 million project when built in 1980.

Inflation is not the only problem. There are changing public values that work against an orderly long-range plan. There are frequent changes in available funds; there are environmental complaints against highway construction; and there are strong desires for public involvement. All of these factors make it difficult to decide which projects should be built first and in what years they should be funded.

The California Department of Public Works finds itself constantly reshuffling the deck trying to maintain a balance between cost and revenue. The conviction grows that searching for ways to stabilize a long-range plan is no longer a productive effort. Instead, why not look for better and quicker ways to respond to change? With this thought in mind, California has undertaken the development of a planning and monitoring system that includes the use of video display terminals for balancing project costs and revenue targets. Operation of the system is described here.

REVIEW OF HIGHWAY FINANCIAL PLANNING

One of the initial steps in California's highway financial planning process is the annual preparation of a 10-year revenue forecast. Money from the forecast is divided among 11 highway districts, primarily by statutory formula. District Engineers have differing needs and will apportion their share of the revenue estimate accordingly. One District Engineer may need to emphasize freeway operations, another spot improvements, and still another resurfacing. There are fixed costs to be set aside, as well,

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for such things as maintenance, administration, and engineering. When all these essential costs have been skimmed off the top, the remaining money is an expenditure target for major construction and right-of-way.

A long-range plan, called a Multiyear Planning Program, is developed following the revenue estimates. This Multiyear Planning Program includes all major highway projects to be built during the next 10-year period. Major projects are generally those in excess of $500,000 construction costs, although projects between $100,000 and $500,000 are included if they are within 3 years of bid opening.

A Multiyear Planning Program is assembled separately for each of the 11 highway districts. Every project selected for inclusion in the Multiyear Program must have a current cost estimate that includes the construction cost at today's prices and the right-of-way cost at today's market value.

An escalated cost is computed by pumping up the value of the current cost to the years where bids would be opened or right-of-way acquired. The escalated cost of every single project must be spread among the appropriate years when the money will be spent. Construction cost might be spread over 3 years, while right-of-way could be spread over 5 or more years.

Finally, the escalated costs of all projects in the Multiyear Program must be summarized and balanced against the revenue targets for each of the 10 years. That is, the sum of all project costs in a given year must equal the revenue target for that year.

Balancing project costs and revenue targets is a cut and try process. Projects are advanced or delayed with each cut until the sum of project costs approximates the available funds targeted for each of the 10 years. There are about 2,400 projects among the 11 districts, with each district balanced separately against its own target.

The task of balancing would be relatively simple were it not for changes and constraints. Frequent changes cause the long-range plan to undergo constant revision. For every project delayed, because of an environmental complaint or stalled negotiations with a local agency, some other project has to be advanced. When this occurs, it is necessary to rebalance the program, but always within the constraints of mandatory apportionment formulas and Interstate deadlines.

The highway financial planner longs to return to the slower pace of a decade ago unless he belongs to the generation that accepts frequent change as a way of life.

The Need for Fast Response

Because the highway transportation picture is changing so rapidly, any kind of a stable program of project selection and funding is virtually impossible to achieve. Still, decisions must be made, budgets must be prepared, and contracts must be awarded as federal and state moneys become available. There is no apparent way to slow down the rate of change because too many external factors (uncontrollable by highway organizations) are making their influence felt.

A substitute for slowing the rate of change would be to speed up the response to change. In either case, the same end result is achieved if rational decisions can be made about where the highway dollars and the man-hours should be spent.

COMPUTER-DRIVEN DISPLAY SYSTEM

There is a growing interest in the use of video computer terminals that permit data entry and display on a remote cathode-ray tube joined to a central computer by cable or telephone line.

A video display terminal (Fig. 1) works somewhat like a typewriter. The keyboards are nearly identical. On a typewriter, the space bar moves the carriage. On a display terminal, the space bar positions a cursor horizontally to indicate where the next character will appear. Separate keys position the cursor vertically. Corrections are easier than with a typewriter. A character is replaced by simply overprinting with a new character. A SEND key causes all data displayed on the screen to be sent to the computer.

The chief advantage of a video terminal is fast response time. Data can be entered, stored, retrieved, and summarized in seconds. With this kind of fast response, an engineer can balance and rebalance project costs against targets without feeling overwhelmed by the frequency of change.

The video display system developed by the California Department of Public Works for balancing project costs retrieves its data from a project data bank stored on direct-access computer files. Information on more than 6,000 projects resides in the data bank. It is used for other purposes besides balancing costs and assembling a multiyear highway planning program. It is, for example, the source of a monthly report to management on the developmental status of all highway projects. It is also the source of a quarterly report to the Federal Highway Administration concerning the status of traffic safety projects.

The video display system, developed expressly for balancing project costs, selects all projects for display that meet the criteria for inclusion in the Multiyear (10-year) Program. Projects selected for display are first retrieved from the data bank and collected in a separate computer data file. Only project descriptions, escalation rates, and cost estimates are displayed, although other data such as accident rates, geometry, and traffic volumes are stored in the data file for use on printed reports.

A project is retrieved and displayed by typing in a request at the video terminal. The requester can specify several different "screen formats" described below.

Screen Formats

Three screen formats are available: the Project Data Screen, the County Summary Screen, and the District Summary Screen. They are shown in Figures 2, 3, 5, and 6.

Variations of the Project Data Screen can be displayed depending on whether a project is funded with all Interstate money, all non-Interstate money, or a combination of both (Figs. 2 and 3).

Each data element on a typical Project Data Screen is shown labeled in Figure 4. All data elements can be updated on the screen except the project identification.

The County Summary Screen is a "read-only" screen. It summarizes all project costs within the specified county. The District Summary Screen summarizes all project costs within the specified highway district. It is a "read-only" screen with the exception of the target line, which can be updated (Figs. 5 and 6).

DISPLAYING AND BALANCING

All of the following methods for manipulating data at the video terminal apply to both right-of-way and construction dollars.

Project Escalation

Construction cost estimates can be escalated independently of right-of-way cost estimates. The computer reads the given escalation rate and looks up a factor for the appropriate year from a stored table. The factors are derived from a modified compound-interest formula. Construction costs are escalated to the first year of construction while right-of-way costs are escalated to each individual year of expenditure.

New Values Option

New dollar values (in $1,000) can be entered in any fiscal year. The computer will accept these as escalated values, but it will calculate the true escalated total by applying the escalation rate to the current cost. If this is different from the sum of the new values entered, the computed escalated total will be displayed on the message line (Fig. 7). This is defined as an unbalanced condition.

Balance Option

When an unbalanced condition occurs, the display station operator has two choices. He can ignore the unbalance and update the file, or he can balance by placing a B on the appropriate line. This will cause the computer to distribute and display the computed escalated values in the same ratio as the original displayed values. By touching

Figure 1. Display station manufactured by Control Data Corporation.

Figure 2. Project Data Screen: I prefix denotes Interstate project.

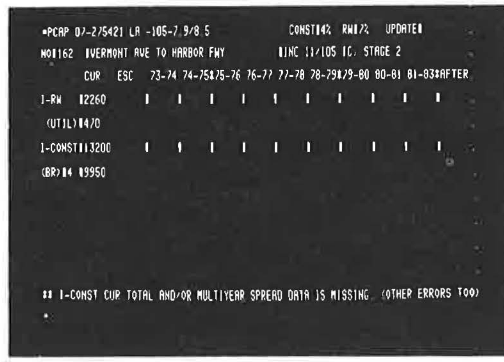


Figure 3. Project Data Screen showing combination Interstate and non-Interstate project.

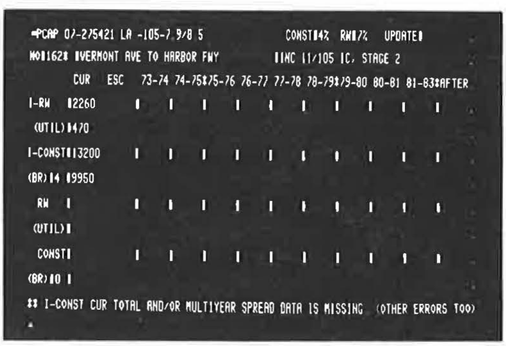


Figure 4. Typical Project Data Screen with labels.

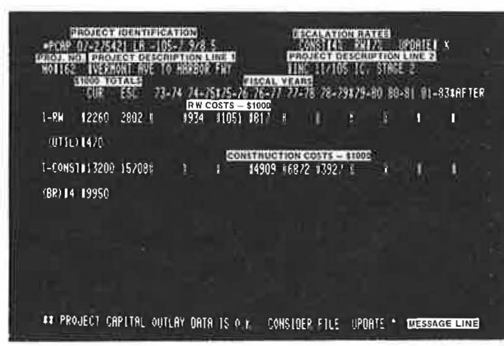


Figure 5. County Summary Screen.

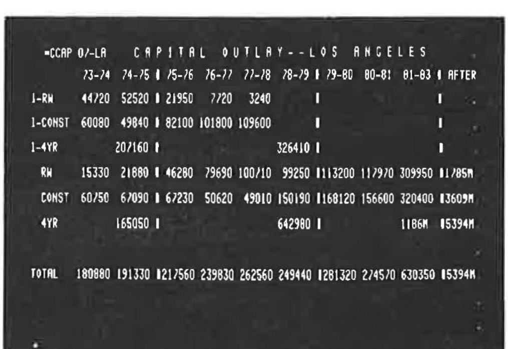
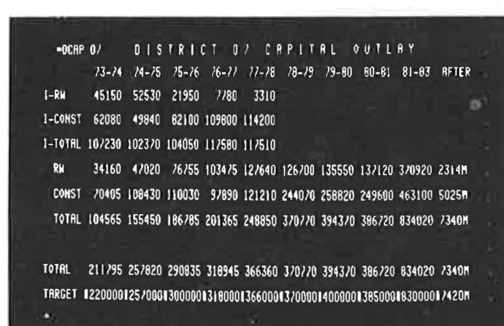


Figure 6. District Summary Screen.



the SEND key on the keyboard, this happens literally in the blink of an eye (Figs. 7 and 8).

Updating the File

As a precautionary measure, the operator is required to take a positive step to update the video data file. To enter data from the Project Data Screen into the video data file, he must place an X opposite the word UPDATE before touching the SEND key; otherwise the display will be returned without updating. The message line tells him when everything is balanced and ready for update by displaying the message "PROJECT CAPITAL OUTLAY DATA IS OK. CONSIDER FILE UPDATE" (Figs. 8 and 9).

Round Option

Ordinarily, all values are displayed in thousands of dollars. If the operator wants to round construction costs to $10,000, he replaces the % sign next to the escalation rate with an R. This tells the computer to round all construction costs to $10,000 (Fig. 10).

Percent Option

Instead of entering new values, the operator may wish to enter percent values assuming, for example, that a certain percentage of the total right-of-way money will be spent in each of several years. The computer will escalate the current cost, apply the percentages, and display the values. Again, it all happens in the twinkling of an eye (Figs. 11 and 12).

Move Option

Balancing capital outlay costs against revenue targets is a trial-and-error process. Some projects are advanced and others delayed. With each iteration, costs approach the target as a limit. Advancing a project means that the money will be spent in earlier years. Delaying the project means that the money will be spent in later years. If, for instance, the operator wants to delay right-of-way and construction expenditures by 2 years, this is accomplished simply by placing an X in the appropriate year (Fig. 13). By touching the SEND key, all right-of-way and construction values are moved to the right 2 years and escalated (Fig. 14). This change, of course, immediately revises the summaries. The operator can move back and forth between project displays and summaries until he zeros in on the target.

Spillover Option

Under some circumstances, especially where the construction estimate is so large (in excess of $10 million) that payments to contractor extend over a 3-year period, the operator may estimate the amount that would be spent during 2 of the years and ask for the balance to be placed in a third year. He does this by placing the character S in the third year (any designated blank year). The computer will compare the sum of the first 2 years with the escalated total and return a screen with spillover placed in the third year (Figs. 15 and 16).

County Summary Screen

At any time, the operator may display the County Summary Screen (Fig. 5) by changing the display code from PCAP (project capital outlay) to CCAP (county capital outlay) and specifying the county. The County Summary will reflect any changes made on the Project Data Screens.

District Summary Screen

Because highway fund money is allocated by statutory formula to each of 11 geographical districts, the District Summary (Fig. 6) is important. Target values can be entered on this screen for comparisons against totals. The District Summary Screen

Figure 7. New values and balance option: New values entered. Message line indicates construction dollars not in balance. Symbol B causes balancing to occur.

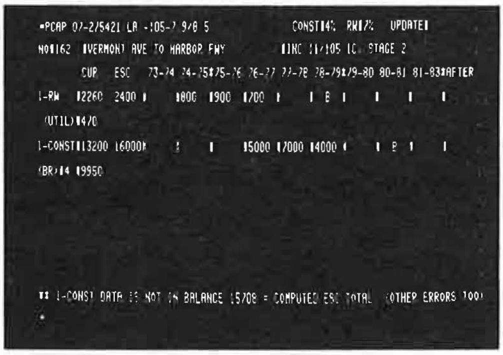


Figure 8. Balance and update options: Balancing has just occurred and operator has placed X in update box ready to update.

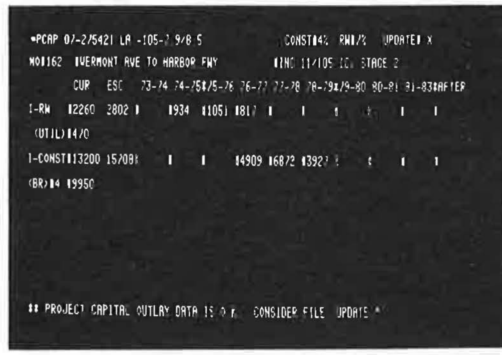


Figure 9. Updating the file: Note message line.

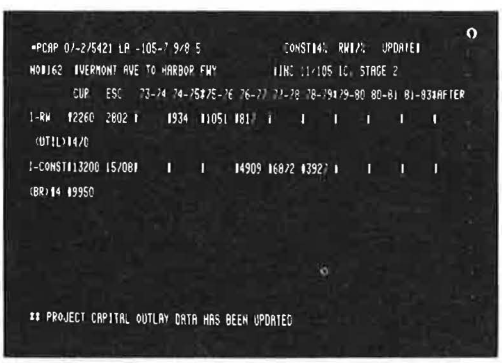


Figure 10. Round option: All dollars rounded to 10,000.

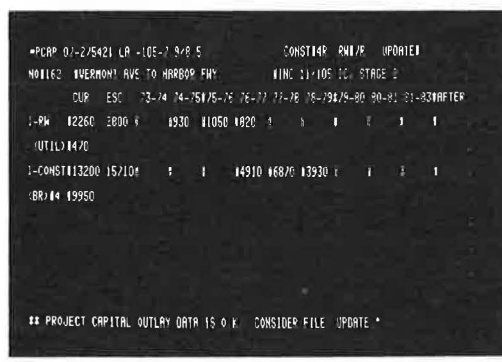
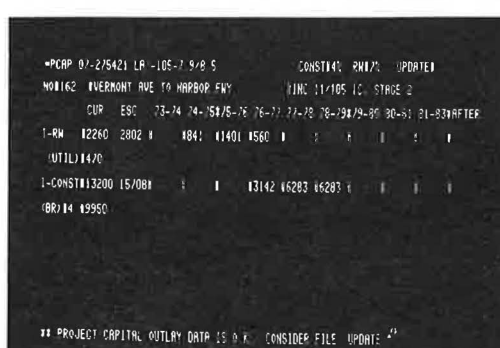


Figure 11. Percent option: Percent values displayed.

Figure 12. Percent option: Just after percent values applied.



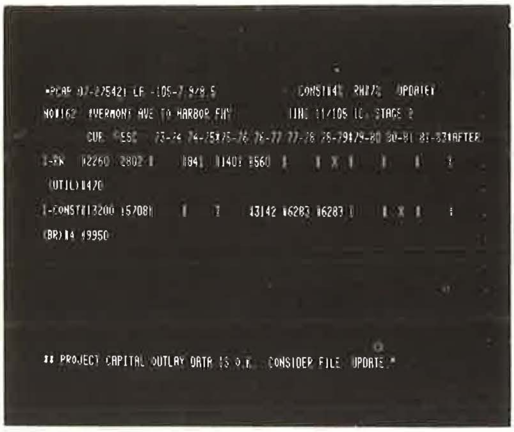


Figure 13. Move option: Operator has just placed X in 78-79 R/W year and 80-81 construction year.

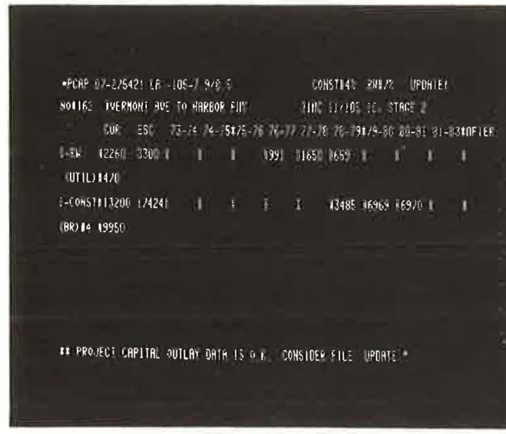


Figure 14. Move option: Dollars have been moved and escalated.

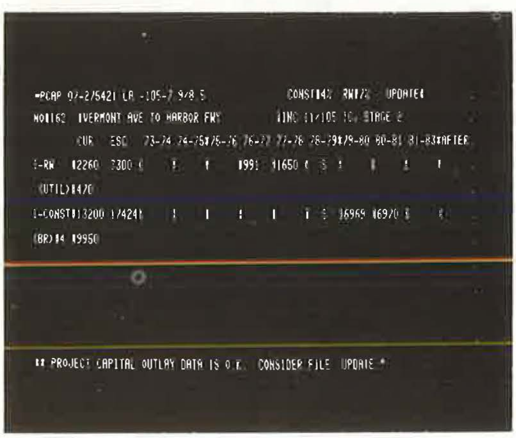


Figure 15. Spillover option: Operator places symbol S in year of his choice.

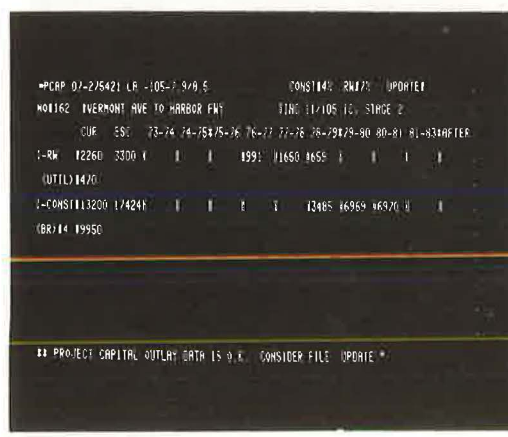


Figure 16. Spillover option: Computer returns screen with balance of computed total placed in S year.

reflects any changes made on the Project Data Screens.

Printed Reports

Any screen display can be printed directly on an electric typewriter connected by cable to the video terminal by simply touching a PRINT key on the video keyboard. This is a convenience for getting quick, hard-copy summaries after making trial balancing runs.

In addition, two formal printed reports can be requested. The first is a list of all projects in the video data file by district, county, and route number. Interstate projects are listed first, followed by non-Interstate projects and finally by a summary.

The second is an individual sheet for each project, which shows, in addition to all the data on the first report, more complete information about each project, such as traffic accident history, geometry, and so forth.

These latter two reports must be printed "off-line." They can be initiated at the video terminal, but they are printed either on the high-speed printer at the central computer or on a medium-speed remote printing terminal located in a district and connected to the central computer by telephone lines.

SUMMARY AND CONCLUSIONS

A technique involving the use of a computer and video display terminals has been developed for balancing highway project costs against revenue targets. The technique is being used in an organization having 2,400 major highway projects in various stages of development. It is successful as a management tool because it offers quick response for decision-making where management operates in an environment of constant change.

Remote video display terminals tied into a central computer give engineers the ability to retrieve from a data bank right-of-way and construction capital outlay estimates and to display them individually by projects and collectively by district or county summaries.

The engineer can enter new values, move capital outlay from one fiscal year to another, escalate values, change escalation rates, resummarize, and initiate printed reports. All of these functions can be done quickly and simply by using a video display terminal with keyboard input.

A year of experience with the system has shown that the time-consuming work of balancing and refining the Multiyear Planning Program under pressure of frequent change is greatly reduced. This is one of the payoffs that helps to offset the rising cost of financial planning for federal and state highway programs.

ACKNOWLEDGMENT

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MEASURING TIME LOSSES AT HIGHWAY BOTTLENECKS AND EMPIRICAL FINDINGS FOR THE CHESAPEAKE BAY BRIDGE

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In this paper a readily implementable procedure is developed for measuring the length of traffic queues and time losses from severe highway congestion. The method is then applied to an actual situation where congestion is so great that 2-lane traffic backups several miles in length are formed. Time losses are calculated for past observations and forecast for future years. Although time loss is a crucial element in highway investment analysis, little attention has been directed to the development and the comparison of alternative measurement techniques. In addition, there are few instances in traffic queuing literature where sophisticated measurement procedures are illustrated with real-world data. In general, the experience of the author has been that where sophisticated mathematical models are used the data are hypothetical and where real data exist the techniques used are deficient.

THE evaluation of highway improvements must give special attention to benefits accruing in the form of time savings. It has been argued and empirically measured by the author that upwards of 90 percent of relevant benefits from highway investments may take the form of time savings (1; see also 5). A readily implementable procedure for measuring and valuing time savings is thus of crucial importance in highway investment decision-making. Although the value of time saved is by no means resolved (6), this paper is directed to the simpler question of how in practice to measure the time saved (i.e., in hours rather than dollars). This determination is thus a prerequisite to the final valuation of time savings and project evaluation.

In addition, the paper will focus on a single highway bottleneck rather than a complete network whose system interrelationships may be considerably more complex. For mathematical convenience the constricting bottleneck is assumed to occur at a point in space. An interval constriction such as a narrow length of highway does little to change the theoretical analysis, however, and is in fact the situation encountered in the empirical findings that follow.

The question addressed is thus how to measure effectively highway congestion time losses when the losses are so great as to cause queuing. The main elements of the measurement involve determining the number of vehicles affected by the congestion (i.e., the queue) and the interval and amount of the time constraint. Average delay is also investigated because the value of travel time may be sensitive to time loss per vehicle.

ARRIVAL AND CAPACITY APPROACH

An intrinsic approach to traffic queue estimation might relate traffic inflows (arrivals) and outflows (capacity) in order to determine those vehicles caught in the bottleneck at a given time. If continuous functions are assumed, the number of vehicles congested at a point bottleneck is

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$$Q(t_1) = \int_{t_0}^{t_1} \left[A(t) - C(t) \right] dt$$

where $Q(t_1)$ is the queue measured in vehicles and A(t) and C(t) are the arrival function and outflow function (capacity) at time t respectively.

Given a smooth arrival function and constant outflow, Figure 1 shows their relationship to the queue function measured as the cumulative area between the A(t) and C(t) functions. The queue starts to form at t_0, is at a maximum at t_1, and ends at t_2. Areas X and Y are thus equal to each other and to the maximum queue length in vehicles.

A fundamental problem with the arrival and capacity approach is the general unavailability of data on both arrivals and capacity. Although parameters of alternative arrival probability distributions could likely be estimated, the application of these functions to specific cases would involve much effort and imprecision. For a discussion of the stochastic process approach see McNeil (4).

In addition to arrivals subject to wide variation and uncertainty, the capacity function itself is not so well behaved. One-way operations, for example, may be put into effect by attendants at the scene of a bottleneck. These not only change capacity greatly, but may be used in an unpredictable and unsystematic way by the authorities on the scene. [Interviews with attendants at the Chesapeake Bay Bridge indicate that decisions to begin and end one-way operations are made by using a flexible decision rule. When traffic backups exceed approximately ½ mile, one-way operations are placed in effect if traffic in the other direction is light. In 1967 there were as many as 9 one-way operations in one day, with some lasting almost an hour. Frequently long backups form in the direction that is stopped, necessitating correctional one-way operations for the direction of light flow.]

Another factor causing a variable capacity is the well-known result in traffic engineering that capacity (defined as maximum traffic volume) is obtained only when the traffic density is "optimal." The precise relationships between traffic speed, volume, and density are somewhat unpredictable, depending mainly on the size of the highway (number and width of lanes) and additional factors such as curves, grades, location, lateral barriers, and traffic lights. An excellent summary of the research done in this area can be found in the Highway Capacity Manual (2).

Typical relationships between traffic volume, density, and average speed are shown in Figure 2. The graphs indicate that, after an "optimal" density D_o, additional vehicles on the highway actually decrease the traffic volume passing over the road or through a bottleneck. Although a unique capacity can be defined for a particular facility (V_o), the actual volume passing through a bottleneck under congested conditions is not constant but also depends on the inflow; A(t) - C(t) is usually a complex and discontinuous function whose integral is solvable only after making numerous simplifying assumptions.

QUEUE FUNCTION APPROACH

From the foregoing analysis it is observed that a procedure bypassing the improper intergral of A(t) - C(t) will be easier and more accurate. Going directly to the length of traffic queues is such an approach and can be easily undertaken by field measurement or survey. The Chesapeake Bay Bridge, a 2-lane facility spanning the Chesapeake Bay at Annapolis, Maryland, was used for such a study. [A second bridge parallel to the existing one was opened in mid-1973 after this study was completed.] A survey of commercial establishments located various distances from the bridge on both sides of the Bay was taken to determine how severe congestion was on various days and at various times of day. More than 15 gasoline station, restaurant, and motel owners were asked (a) whether traffic ever backed up to their establishment, (b) when and how often, and (c) how long traffic remained queued up on the busiest days. Aside from some confusion over the precise meaning of traffic backup, most of those interviewed were able to answer the questions. Their answers showed remarkable consistency when compared with one another and with their respective distances from the bridge. In cases of discrepancy the lower estimate was taken because most of those interviewed, being in favor of a new bridge, would likely tend to exaggerate the problem. To increase accuracy and consistency of responses, only the days of worst congestion were asked for.

With an assumption of vehicles per mile per lane (175 vehicles, for example, allows around 30 feet for each vehicle and spacing), the length of the queue (in vehicles) was determined for any given time during the most congested days. The total waiting time for all vehicles for a given direction and day is simply

$$\int_{t_0}^{t_1} Q(t)\, dt$$

where $Q(t)$ is the queue function, t the time of day, and t_0 and t_1 the times when the queue begins and ends respectively. Average delay for a given queue period may be determined by dividing time loss by traffic volume. Queue lengths are shown in Figure 3. Points are connected by straight lines; dotted lines are hypothesized extrapolations where no data were available.

TIME LOSS CALCULATION

Adding together the areas under each curve yields the nucleus of waiting time or time lost (in vehicle-hours) by all traffic using the bridge on the busiest summer weekends in 1967. The actual calculation of time loss on the Chesapeake Bay Bridge involved two slight adjustments to the simple area under the queue functions. Since the areas represent the time loss from a bottleneck considered as a point instead of a range, the time lost while on the bridge (within the bottleneck) must be added to that lost waiting to enter the bottleneck.

The second adjustment is a subtraction accounting for the fact that all the time loss is not saved by eliminating congestion. Since it takes vehicles some time to cover the queue distance with no congestion, a subtraction must be made to obtain actual time savings. For the queue time loss adjustment it was first necessary to calculate the average queue length (AQL), in vehicles:

$$AQL = \frac{\int Q(t)\, dt}{\text{number of hours queue exists}}$$

The average queue distance is calculated in miles as

$$AQD = \frac{AQL}{\text{vehicles per mile}}$$

The time adjustment may thus be computed assuming some average speed (for example, conditions of free traffic flow with no congestion). The subtraction for the bottleneck distance is obtained directly when the range of bottleneck is known.

Based on the queue functions in Figure 3 and these adjustments, the time loss for the busiest summer weekend periods in 1967 was calculated. Table 1 gives these results for the 5 weekend congestion time categories.

In aggregating for the whole year it is necessary to decide which days qualify as the busiest days and what adjustments to make for days when less than maximum congestion existed. Losses during holidays and days of minor congestion where interference occurs but no queues actually develop must also be included in any actual time loss calculation. The results of all assumptions and adjustments for 1967 Chesapeake Bay Bridge data are given in Tables 2 and 3. It is readily apparent that the congestion problem is a severe weekend peak-load phenomenon, with most of the time loss occurring on the summer weekends. Since most of the time loss results from summer weekend queues, non-peak-period congestion is of little consequence in computing the yearly totals.

Figure 1. Arrival and outflow functions.

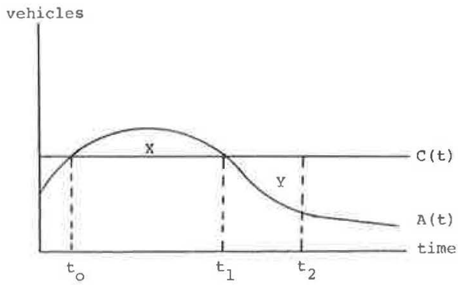

Figure 2. Volume, density, and speed relationships.

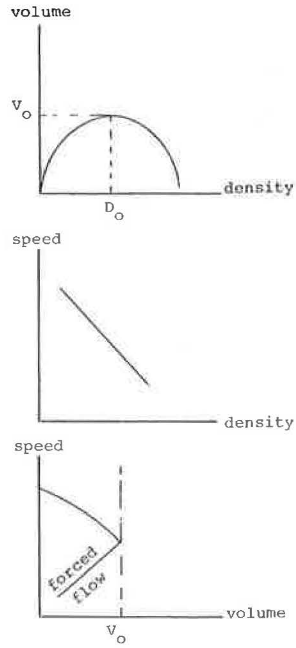

Figure 3. Queue functions for the Chesapeake Bay Bridge in 1967. Lines 1, 2, 3, 4, and 5 represent Friday eastbound, Saturday eastbound, Saturday westbound, Sunday eastbound, and Sunday westbound respectively.

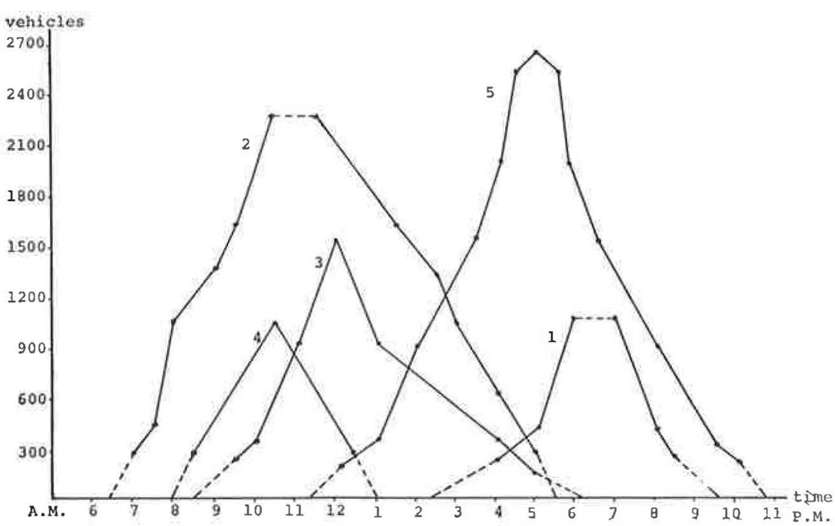

Table 1. Maximum summer weekend time loss.

Period and Direction	Total Time Loss (hours)	Average Time Loss[a] (hours per vehicle)	Peak-Period Average Time Loss[b] (hours per vehicle)
Friday eastbound	4,573		
Saturday eastbound	15,431	1.2	1.6
Saturday westbound	6,905		
Sunday eastbound	3,496		
Sunday westbound	14,334	1.0	1.7

[a]Average delay for all vehicles during the total queue period.
[b]Average delay for vehicles entering the queue at its longest.

Table 2. Total time loss for 1967.

Day	Time Loss (vehicle-hours)	
Holidays		17,246
July 4th period	1,390	
Memorial Day	540	
Labor Day period (2 days)	11,836	
Thanksgiving weekend	2,640	
Christmas and New Years	840	
Miscellaneous days		24,815
Summer weekends		507,909
Total		549,970

Table 3. Monthly time loss and traffic for 1967.

Month	Traffic Volume (thousands of vehicles)	Time Loss (hours)	Ratio (time loss per vehicle)
January	242	830	0.0034
February	197	690	0.0035
March	292	1,640	0.0056
April	324	1,180	0.0129
May	364	23,330	0.0641
June	498	120,450	0.2419
July	637	194,040	0.3046
August	604	144,900	0.2399
September	417	50,960	0.1222
October	344	3,450	0.0100
November	332	3,900	0.0133
December	293	1,600	0.0055
Total	4,544	549,970	0.1210

Source: Traffic volume obtained from the Maryland State Roads Commission.

Table 4. Predictions for traffic and congestion time losses during the May-September period.

Year	Traffic (thousands of vehicles)	Time Loss (thousands of vehicle-hours)
1967[a]	2,520	532
1967	2,578	
1968[a]	2,772	
1968	2,696 (5.4%)[b]	642
1972	3,336	1,046
1973	3,500 (4.9%)	1,150
1980	4,852 (4.3%)	2,001
1990	7,370 (3.8%)	3,588
2000	10,740	5,585

[a]Actual observations.
[b]Percentages in parentheses give annual compound growth rates between selected dates. Traffic grew at an annual rate of 6.3% during the 15-year observation period.

Calculation of the time loss for 1967 (a major part of the benefits if a wider bridge had existed for that year) is an intermediate step in determining the benefits from an expanded bridge investment. In order to predict time losses for future years, it is necessary to relate congestion to yearly traffic volume for more than one observation. Given traffic for a future year, the expected time loss can thus be calculated, and, alternatively, the time loss-traffic volume relationship helps to predict the future traffic demand itself. The association between the variables is two-way, with traffic volume dependent on many variables, including congestion. A multivariate traffic-demand regression model developed by the author (1) was used to generate the interdependent traffic and time-loss forecasts. These are given in Table 4.

CONCLUSION

This paper has attempted to develop and illustrate a simple and accurate technique for measuring time losses resulting from severe congestion in traffic queues. It is readily apparent from the empirical findings applied to the Chesapeake Bay Bridge that time saved by eliminating traffic queuing at bottlenecks may involve enormous magnitudes. For example, in 1980 over 2 million vehicle-hours would be saved by eliminating the congestion. It is hoped that the time-loss estimation technique developed will contribute toward a more refined measurement of a very important benefit component in highway investment decision-making.

REFERENCES

1. Agnello, Richard J. The Second Chesapeake Bay Bridge: A Cost-Benefit Study in Public Highway Investment. Johns Hopkins Univ., PhD dissertation, 1970.
2. Highway Capacity Manual—1965. HRB Spec. Rept. 87, 1965.
3. Maryland State Roads Commission. Chesapeake Bay Bridge and Ferry Studies.
4. McNeil, D. R. Growth and Dissipation of a Traffic Jam. Transportation Research, Vol. 3, No. 1, April 1969, pp. 115-121.
5. Mohring, H., and Harwitz, M. The Nature and Measurement of Highway Benefits: An Analytical Framework. Northwestern Univ. Press, 1961.
6. Owen, John D. The Value of Commuter Speed. Western Economic Jour., Vol. 7, No. 2, June 1969.

ACCIDENT COSTS: SOME ESTIMATES FOR USE IN ENGINEERING-ECONOMY STUDIES

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The primary objective of this paper is to devise and implement a procedure for estimating accident costs, based on cost data developed by several state highway departments, that are readily applicable for use in engineering-economy analysis. The overall approach is to generate weighted averages for the costs of accidents wherein the estimates from previous studies provide the direct cost input and the 1969 Texas accident experience provides the weights to be assigned to these costs. Direct costs include property damages, medical costs, legal and court fees, values for loss of work time and loss of vehicle use, and damages awarded in excess of costs. An involvement is that portion of an accident relating to a single vehicle and the death, injury, or property damage associated with it. Using the involvement as the basic statistical unit, the data are cross-classified by various combinations of accident severity, vehicle type, and accident type. For each of the resulting categories, the cost components are adjusted by price index inflators, and a mean involvement cost is calculated from these adjusted data. In addition to the direct cost per involvement, another type of cost, the present value of expected future earnings, is estimated for involvements where persons were fatally injured. An estimate for the cost of an accident can be obtained by combining the appropriate direct cost for the vehicles involved with the present value of future earnings lost due to fatalities occurring in the accident.

•IN 1949, the Bureau of Public Roads published a manual of procedures that was to serve as a guide in conducting comprehensive statewide research on motor-vehicle accident costs (1). The study design, which implemented recommendations developed by a committee of the Highway Research Board, was to provide data for the following purposes:

1. The determination of those costs of motor-vehicle accidents that might be saved for the vehicle owner by the elimination of accidents;
2. The determination of all other costs of motor-vehicle accidents, including expenditures made to prevent accidents or to protect against liability for damages and losses;
3. The correlation of certain characteristics of accidents for which adequate summaries are not generally available, such as age and sex of driver;
4. The establishment of general accident rates, such as commercial vehicle accidents per unit of travel compared with similar rates for passenger cars; and
5. A contribution to other studies being conducted through the Highway Research Board.

To date, five states have completed and published the results of studies based on the framework described in the BPR manual (2, 3, 4, 5, 6). In addition to providing a large quantity of detailed data, some of these studies have served as the data base

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for papers published by the HRB (6, 7, 8, 9). In spite of the amount of work that has been accomplished regarding these accident-cost studies, there exists a data gap with regard to readily accessible cost information that can be used as coefficients in engineering-economy analyses (exceptions include 4, 10, 11).

The purpose of this paper is to present some of the results of a larger study conducted at the Texas Transportation Institute under the sponsorship of the Texas Highway Department and the Federal Highway Administration (14). The cost estimates presented here were developed to serve as input data for use in benefit-cost, cost-effectiveness, and other types of engineering-economy models.

The data base used is a combination of the information collected by the states of Utah, New Mexico, Massachusetts, and Illinois (hereafter referred to as the data states). In the aggregate, over 19,000 accident involvements and their associated costs and characteristics composed the data base. To complement this information, data describing the Texas accident experience in 1969 (a total of more than 544,000 involvements) were used to develop a weighting system for the construction of the accident cost series.

BASIC CONCEPTS AND DEFINITIONS

Each of the studies by the data states was the product of an extensive questionnaire-interview process in which individuals involved in accidents were queried to determine the direct cost of their portion of the accident. Each of the data states made its raw information available to the BPR, and in 1968 the Bureau compiled and reorganized the data to ensure mutual compatibility. These data were provided by the BPR for use in this study and serve as the basis for the cost estimates presented here.

A traffic accident is any accident involving one or more motor vehicles in motion that occurs on a traffic-way and results in death, injury, and/or property damage. Ideally, the determination of accident costs would be made using the individual traffic accident as the basic statistical unit over which a sample would be taken. However, such a procedure is operationally difficult and costly to implement when more than a single vehicle is involved. Consequently, an alternative procedure was developed using the involvement rather than the accident as the basic statistical datum.

An involvement is that portion of an accident relating to a single vehicle and the death, injury, and/or property damage associated with that vehicle. By way of example, assume that a car collides head-on into a truck, resulting in death, injury, and property damage in the car and property damage only in the truck. Such an outcome produces a fatal car-truck accident and two involvements: a passenger car involvement and a truck involvement. The accident-involvement dichotomy is of critical importance in derivation of cost estimates and is discussed further in a later section.

The criteria for the selection of the elements to be included in the cost estimates are based on the distinction between direct and indirect costs (1, p. 9 et seq.). In general, direct costs include the following major components: (a) property damages to vehicles, vehicular cargoes, and nonvehicular property; (b) medical costs, including doctor's fees and charges for hospitals, drugs, medicines, appliances, and ambulance service; (c) legal and court costs; (d) value of work time lost due to nonfatal injuries; and (e) miscellaneous costs. In summary, direct costs include those expenses (primarily "out-of-pocket") that can be directly attributable to accident occurrences.

Indirect costs are the "money value of damages and losses to persons and property that are the indirect result of accidents" (1, p. 9) and include items such as loss of future earnings due to fatal injury, loss of use of vehicle, accident prevention activities, et al. Since the data states relied exclusively on the direct cost components as the sources for their cost estimates, little will be said about indirect costs. There is, however, at least one indirect cost item—the loss of future earnings due to fatal injury—that should be discussed if for no other reason than the magnitude of the dollar value it entails. The loss of future earnings due to death represents the dollar amount of potential goods and services that is lost to society when one of its members dies. The introduction of such an item brings forth, at least implicitly, the notion of a measurement for the value of a human being and all its attendant moral and philosophical trappings. At any rate, the decision to include or exclude the loss of future earnings has a very significant impact on the estimated costs of fatal involvements and accidents. For example, in the Ohio study (4, p. 32) the estimated direct cost per fatal passenger car involvement is $4,236. In the Washington Metropolitan Area Study (11, p. 77), the inclusion of loss of future earnings led to a cost per fatal passenger-car involvement estimated at $49,435.

In reflecting only the direct costs, the cost for fatalities generated by the data states might be interpreted as representing some set of minimum values. To these minima could be added an estimate for loss of future earnings. The result would be a more comprehensive estimate of the costs of fatal accidents and involvements.

RESEARCH METHOD

Briefly summarized, the method used to derive a set of cost estimates for use in engineering economy studies is as follows:

1. Calculate the average (mean) direct cost of an involvement;
2. Utilize accident-involvement ratios (based on the 1969 accident experience in Texas) to convert direct costs per involvement to direct cost per accident;
3. Calculate the average loss of future earnings (using the age and sex distribution of fatally injured persons in Texas in 1969) per fatal accident; and
4. Add the value in step 3 to the costs for fatal accidents in step 2.

General Considerations and the Data System

Underlying this method of determining the cost estimates for involvements and accidents is the notion that the magnitude of the direct costs is dependent on (a) the cost per unit of the relevant components (e.g., dollars per hospital day, dollars per wrecker haul, dollars per hour of mechanical labor) and (b) the number of units involved (e.g., 20-day hospital stay, 50-mile wrecker tow, 3 hours' labor in repair shop). The number and type of such units that result from an accident are partly a function of the physical characteristics of the accident, such as the number of vehicles involved, type and manner of collision, number and type of personal injuries, vehicle speed, and so forth. What is being sought is a selection of the physical characteristics that will allow a categorization that tends to group accidents similar in cost.

The characteristics obtained to systematize the cost data were chosen on the basis of (a) their hypothesized importance in determining involvement costs and (b) the type of information available from the data states. For example, vehicle speed reasonably could be hypothesized as an important determinant of involvement costs, i.e., the higher the speed of the involved vehicle, the higher the involvement cost. Nevertheless, since vehicle speeds are not among the information comprehensively provided by the data states, direct classification of involvements according to speed is not possible. A less direct way of accounting for the influence of speed on the resulting costs is possible by using a rural-urban dichotomy, because rural travel implies higher speeds than urban travel. As a result, the classification system that is used here reflects the need to combine analytical categories with categories determined by data availability. [A more complete classification system is presented elsewhere (14); in addition to the severity, accident type, and vehicle type developed here, the categories of accident location (rural-urban), highway type, and highway system are included.]

The most important characteristic of an accident is probably its severity. Whether persons were killed, injured, or unharmed affects the magnitude of both the direct and indirect costs. A classification of fatal, injury, or property damage only (PDO) would be expected to show increasing costs from the least severe (PDO) to the most severe (fatal). Because, in the studies made by the data states and in this paper, the entire system of classification of involvements revolves around the severity category, it is of some importance that costs-per-involvement for a given severity be approximately the same in each of the data states. If this is so, the data from the four studies can be combined and treated as a single data system from which the direct cost of an involvement having certain physical characteristics can be adequately estimated by the average (mean) cost of other like involvements.

In addition to severity, two other physical characteristics—accident type and vehicle type—were selected on which to classify involvements for calculating their average costs. Accident type refers essentially to the manner in which an accident occurred. To a larger degree, it also indicates whether the accident involved one vehicle or several vehicles. Thirteen types of accidents were codified by the data states and used for the present paper (Table 1). They include head-on, sideswipe, turning, and rear-end collisions, which involve more than one vehicle, as well as collisions of single motor vehicles with pedestrians, bicycles, trains, animals, fixed objects, and other objects.

The type of vehicle characteristic permits classification of involvements on the basis of passenger car, single-unit truck (e.g., pickup, bobtail), and combination-unit truck.

Using these three characteristics—severity, accident type, and vehicle type—an analysis of variance was made to compare the costs of like involvements among the four data states. The results indicated that, at the 5 percent level of confidence, there was no significant difference in the mean involvement costs among the data states for similar involvements. The raw data from the data states were combined and subsequently treated as a single data system.

To treat the information from the data states as a single, combined data base, it is necessary to aggregate the data in a manner compatible with the sampling procedures used by those states. To this end, the statistical treatment of the resulting combined data base is somewhat constrained. Such constraint is manifested in the following manner: Involvements must first be segregated into severity classes before further classification is accomplished, and, inversely, severity classes cannot be combined in the process of deriving involvement cost estimates. This procedure is used because, in the context of a combined single data base, the sampling rates of the individual states cannot be utilized in determining mean involvement costs. These rates, which permitted the individual states to aggregate across different severities, were determined by the accident experience of the respective states and (along with the resulting expansion factors that were used to expand state samples into state totals) have quantitative meaning only with respect to the individual state. On the other hand, when the involvements of the data states are grouped by severity, the implicit assumption is that these involvements are from statistical populations that include only involvements of like severity. Thus, a fatal involvement in Illinois and a fatal involvement in Utah are viewed as equivalent observations from the population of fatal involvements.

The most important aspect of this treatment is the limitation it places on the interpretation of the resulting mean cost estimates. Although it is possible to determine the mean cost of selected involvements of like severity, it is not possible to derive the mean cost of selected involvements of differing severities. In the former case, the involvements are equally weighted; in the latter, no weights can be assigned since the exact nature of the quantitative relationship (in the combined data system) among the severity categories cannot be specified due to the different sampling rates selected for the original individual state studies.

Price Adjustments

In determining the average cost of involvements, the direct cost components must be adjusted via a price index in order to convert costs into comparable magnitudes. Because governmental price indexes are not constructed on an individual state basis, adjustments for relative cost differentials among the states cannot be made. To adjust for price differentials due to time differences and to put all the cost data on a comparable basis, two price indexes are used—the overall Consumer Price Index and the medical cost component of the Consumer Price Index. [The individual studies were conducted in 1953, 1955-7, 1955-6, and 1958. All the data were adjusted to 1969 levels.] The direct-cost items containing medical, hospital, physician, and nursing fees are adjusted by the medical cost component of the Consumer Price Index. All other direct costs are adjusted by the overall index. After the direct costs are adjusted for price level changes, the mean cost of the involvement (as defined by the severity, accident type, and vehicle type) is calculated. The results are given in Tables 1 and 2.

Table 1. Direct cost in dollars per involvement for passenger cars by accident type and severity, from data states.

	Severity		
Accident Type	Fatal	Injury	PDO
Multi-vehicle			
Head-on	8,593	1,518	235
Std. error	1,469	223	11
Rear-end	6,482	1,000	161
Std. error	1,432	62	4
Angle	6,505	950	198
Std. error	644	42	5
Sideswipe	6,946	594	131
Std. error	2,299	80	9
Turning	5,232	945	169
Std. error	1,439	87	6
Parking	–	485	66
Std. error	–	95	3
Other	7,731	862	123
Std. error	4,523	161	6
Single vehicle			
Pedestrian	5,395	1,441	28
Std. error	329	206	5
Train	6,846	1,834	439
Std. error	986	733	163
Bicycle	4,518	1,006	61
Std. error	678	402	13
Animal	3,066	1,878	308
Std. error	1,650	424	23
Fixed object	3,057	1,934	273
Std. error	308	278	19
Other object	5,578	1,139	91
Std. error	4,262	164	2
Non-collision[a]	3,909	1,681	219
Std. error	508	118	12
All	5,574	1,137	165
Std. error	295	40	2

[a]For example, vehicle running off the road or overturning.

Table 2. Direct cost in dollars per involvement for single-unit and combination trucks by accident type and severity, from data states.

	Severity by Truck Type					
	Single-Unit			Combination		
Accident Type	Fatal	Injury	PDO	Fatal	Injury	PDO
Multi-vehicle						
Head-on	5,897	1,567	425	6,705	5,313	1,273
Std. error	1,887	204	72	1,542	1,966	496
Rear-end	4,372	561	113	6,076	796	190
Std. error	1,399	58	11	3,281	271	46
Angle	7,269	728	164	6,689	1,659	386
Std. error	1,149	55	9	2,876	846	93
Sideswipe	3,199	933	101	–	477	83
Std. error	2,847	336	11	–	143	24
Turning	5,068	735	120	3,761	1,818	102
Std. error	1,977	96	7	1,128	1,145	35
Parking	–	306	66	–	665	145
Std. error	–	150	16	–	638	74
Other	1,017	751	111	1,134	239	384
Std. error	417	188	18	703	124	200
Single-vehicle						
Pedestrian	4,685	1,370	–	4,615	1,625	–
Std. error	571	219	–	1,154	358	–
Train	12,524	3,017	1,206	–	8,056	1,670
Std. error	3,342	1,177	482	–	2,256	685
Bicycle	3,978	761	41	3,000	285	–
Std. error	1,273	297	11	897	121	–
Animal	1,738	2,018	348	–	6,891	1,529
Std. error	1,234	747	45	–	5,651	902
Fixed object	7,469	1,908	545	15,706	7,671	2,198
Std. error	1,568	1,248	55	5,497	3,989	769
Other object	–	752	75	–	311	105
Std. error	–	271	15	–	146	22
Non-collision	3,310	2,212	847	12,184	6,488	2,924
Std. error	596	288	93	2,071	1,038	673
All	5,274	951	193	6,698	2,073	695
Std. error	411	43	8	918	332	97

Loss of Future Earnings

To derive a measure for the loss of future earnings for fatally injured persons, estimates are made using data developed by Weisbrod in his analysis of the economic costs of diseases (12, 13). Weisbrod's present values of net future earnings (discounted value of expected future earnings minus expected consumption) are adjusted by the Consumer Price Index to bring the data up to 1969. To convert Weisbrod's data into estimates due to highway fatalities, the age and sex composition of those persons killed in Texas accidents in 1969 is used to calculate a weighted mean representing the loss attributable to a highway fatality.

Although the price index adjustment is assumed to be correct for increases in earnings (including inflationary and productivity changes), two other factors probably cause the resulting estimates to be undervalued. The first of these is due to changes in life expectancies. Weisbrod's calculations employed actuarial data obtained in 1961. In the ensuing years life expectancies have lengthened, and current estimates based on his data are probably undervalued. Second, by deducting personal consumption expenditures from earnings, Weisbrod chose to ignore the value to a deceased person of his own consumption activities. An alternative to this approach would have been to use the present value of gross future earnings, which is philosophically different from and yields quantitatively larger results than the method used herein. At any rate, the net effect of these two factors is to generate values for losses of future earnings due to fatalities that are smaller than they might or should be. The resulting estimates are given in Table 3.

ACCIDENTS AND ACCIDENT COSTS

Utilizing the involvement cost and loss of future earnings data, a set of accident cost estimates can be derived for selected accident categories. Limitations of involvement cost data restrict the discussion of accident costs to three types: (a) passenger car accidents (single and multi-vehicular); (b) truck accidents (single and multi-vehicular); and (c) car-truck accidents (multi-vehicular only). The development of these accident cost estimates is, briefly, the result of combining the direct involvement costs and indirect costs into a weighted average cost—the weights having been determined from the accident experience in Texas in 1969. The procedures used to develop Tables 4 through 7 are discussed below.

Truck Accidents

Since truck involvement and involvement cost data are available for single-unit and combination trucks, the direct cost estimates for all truck involvements are weighted averages of the direct costs of single-unit- and combination-truck involvements. The weights used in deriving these weighted averages are based on the relative proportions of the two types of trucks involved in accidents in Texas. Thus, for example, the direct cost of a truck-pedestrian fatal accident would be the sum of the cost of a single-unit truck-pedestrian involvement (multiplied by the percentage that single-unit involvements are of total truck involvements) and the cost of a combination-truck-pedestrian involvement (multiplied by the percentage that combination-truck involvements are of total truck involvements).

In the case of single-vehicle accidents, there is no difference between involvement costs and accident costs. For multi-vehicular accidents, the estimated accident costs are some multiple of the involvement costs. In the case of truck-only accidents, it is assumed that 2 trucks are involved per multi-vehicle accident. This assumption gives a downward bias to the estimates of this kind of accident since some truck accidents undoubtedly involve more than 2 trucks. However, in the absence of the precise data, the assumption of 2 trucks per multi-vehicular truck accident is used.

Passenger Car Accidents

As in the case of trucks, a single-vehicle passenger car accident is equivalent to an involvement. Thus, accident costs for single-car accidents are the same as the involve-

Table 3. Weighted average of present values of net future earnings in dollars, discounted at 10 percent and 4 percent, for persons killed in Texas accidents, 1969.

	Present Value	
Persons Killed	10 Percent Discount	4 Percent Discount
Male	23,200	45,200
Female	16,900	33,300
All	21,300	41,600

Table 4. Direct cost in dollars per fatal accident by accident type and vehicle-type combination in Texas, 1969.

	Vehicle-Type Combination			
Accident Type	Car	Car-Truck	Truck	All
Multi-vehicle				
Head-on	18,152	14,809	12,432	16,516
Rear-end	14,229	11,516	10,068	12,093
Angle	13,219	13,591	14,172	13,413
Sideswipe	14,760	10,145	6,398	12,799
Turning	10,584	9,891	9,318	10,242
Parking	—	—	—	—
Other	7,731	—	2,104	6,392
All multi-vehicle	14,635	13,198	10,775	13,781
Single-vehicle				
Pedestrian	5,395		4,674	5,279
Train	6,846		12,524	8,119
Bicycle	4,518		3,000	4,281
Animal	3,173		1,738	2,446
Fixed object	3,057		8,842	4,108
Other object	5,578		—	—
Non-collision	3,909		5,402	4,283
All	7,780	13,198	7,478	8,627

Table 5. Direct cost in dollars per injury accident by accident type and vehicle-type combination in Texas, 1969.

	Vehicle-Type Combination			
Accident Type	Car	Car-Truck	Truck	All
Multi-vehicle				
Head-on	3,091	3,744	4,452	3,341
Rear-end	2,071	1,596	1,192	1,932
Angle	1,915	1,759	1,618	1,873
Sideswipe	1,227	1,398	1,608	1,302
Turning	1,901	1,821	1,752	1,875
Parking	967	828	668	923
Other	1,755	1,137	1,428	1,722
All multi-vehicle	1,994	1,856	1,745	1,955
Single-vehicle				
Pedestrian	1,441		1,381	1,433
Train	1,834		4,127	2,242
Bicycle	1,006		755	974
Animal	1,878		2,684	2,031
Fixed object	1,934		1,948	1,942
Other object	1,139		215	1,072
Non-collision	1,681		2,952	1,839
All	1,879	1,856	2,393	1,917

Table 6. Direct cost in dollars per property-damage-only accident by accident type and vehicle-type combination in Texas, 1969.

	Vehicle-Type Combination			
Accident Type	Car	Car-Truck	Truck	All
Multi-vehicle				
Head-on	470	766	1,062	595
Rear-end	320	282	242	310
Angle	416	375	354	405
Sideswipe	258	229	196	246
Turning	338	287	236	321
Parking	132	135	139	133
Other	135	236	226	152
All multi-vehicle	316	331	287	318
Single-vehicle				
Pedestrian	—		—	—
Train	439		1,367	685
Bicycle	61		38	58
Animal	308		607	373
Fixed object	273		1,018	381
Other object	91		82	89
Non-collision	219		1,407	499
All	305	331	679	334

Table 7. Cost in dollars per reported accident for all severities by accident type and vehicle-type combination in Texas, 1969, with loss of future earnings discounted at 4 percent.

	Vehicle-Type Combination			
Accident Type	Car Only	Car-Truck	Truck Only	All
Multi-vehicle				
Head-on	3,100	4,000	4,500	3,500
Rear-end	600	700	1,200	700
Angle	900	1,100	1,200	900
Sideswipe	400	400	500	400
Turning	700	800	900	700
Parking	200	200	200	200
Other	400	300	400	400
All multi-vehicle	800	1,000	600	800
Single-vehicle				
Pedestrian	5,000		5,800	5,100
Train	6,000		8,500	6,600
Bicycle	2,100		2,100	2,100
Animal	500		1,000	600
Fixed object	1,500		2,500	1,600
Other object	400		200	400
Non-collision	1,800		3,300	2,100
All	1,000	1,000	2,000	1,100

ment costs. For multi-vehicular accidents involving passenger cars, costs are determined by (a) assuming the involvement of one passenger car per car-truck and car-other accident; (b) subtracting from total passenger car involvements (of a given severity and accident type) the number of cars involved in car-truck and car-other accidents; and (c) dividing the residual determined in (b) by the number of passenger-car-only accidents (by accident type) to determine the average number of passenger cars involved in the respective types of multi-vehicular accidents. For example, there are 731 passenger cars involved in fatal head-on accidents. There were 176 car-truck, 10 car-other, and 258 car-only fatal head-on accidents. If one car is involved per car-truck and car-other accident, there were 545 cars involved in the 258 car-only accidents. This results in an average of 2.11 cars per fatal head-on accident.

The accident costs for the car-only accidents, then, are obtained by multiplying the average number of cars involved in accidents (of given severity and accident type) by the costs per car involvement in those accidents.

Car-Truck Accidents

The accident cost of a car-truck accident is the sum of the cost per truck involvement and cost per car involvement, since it is assumed that only one car and one truck are involved. As is the case of truck-only, multi-vehicular accidents, this assumption gives a downward bias to the cost per car-truck accident since there probably are some of these accidents involving two or more cars or trucks.

Because no appropriate involvement cost estimates were available from the data states, no accident cost estimates have been derived for those accidents (2 percent of all Texas accidents) involving vehicles other than cars-only, trucks-only, and cars-trucks.

In computing weighted averages for accident costs including loss of future earnings (Table 7), it is assumed that (a) in pedestrian and bicycle fatal accidents only one fatality occurs per accident and (b) for all other accident types the number of fatalities that occur per accident is 1.26. This average was obtained by prorating the fatality data in Texas, having allowed for the occurrence of one fatality per pedestrian accident and per bicycle accident.

LIMITATIONS OF THE DATA

While the accident costs developed in this paper may be useful as inputs in engineering-economy analyses, they are not without their limitations. The potential user of these estimates should at least keep in mind the following:

1. The weights, as derived from the 1969 accident experience in Texas, may not be valid for some uses.
2. Changes in vehicle operating speeds, vehicle design, and highway design may have caused changes in the involvement costs that are not adequately reflected in these estimates.
3. In the absence of more detailed information, the data in Table 7 were developed assuming 1.26 fatalities per accident (except in the cases of pedestrian and bicycle accidents). Consequently, a special caveat is in order regarding their use, although the data are illustrative of the results obtained from following the procedures detailed in this paper.

SUMMARY AND CONCLUSIONS

This paper has presented some of the accident cost information developed in a comprehensive study that made use of extensive data developed in four statewide accident cost studies together with other information covering all accidents in Texas in one year.

It is the authors' opinion that the accident costs provided in this paper will be quite useful as inputs in engineering-economy studies. These accident costs have at least three advantages over other comparable cost estimates currently available in the literature:

1. They are provided on a cost-per-accident basis,
2. They are updated to recent times, and
3. They cover a much larger sample than any other estimates now available.

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REFERENCES

1. A Proposed Study for the Determination of the Cost of Motor Vehicle Accidents. U.S. Bureau of Public Roads, 1949.
2. Cost of Motor Vehicle Accidents to Illinois Motorists, 1958. Illinois Department of Public Works and Buildings, Division of Highways, 1962.
3. The Economic Costs of Motor-Vehicle Accidents. New Mexico State Highway Department.
4. Ohio Department of Highways. The Analysis of Motor Vehicle Accident Costs in the State of Ohio. Ohio State Univ., 1970.
5. Economic Cost of Motor Vehicle Accidents. Utah State Department of Highways.
6. Dunman, R. Economic Cost of Traffic Accidents in Relation to the Human Element. HRB Bull. 263, 1960, pp. 40-49.
7. Billingsley, C. M., and Jorgenson, D. P. Direct Costs and Frequencies of 1958 Illinois Motor-Vehicle Accidents. Highway Research Record 12, 1963, pp. 48-76.
8. Dunman, R. Economic Costs of Motor Vehicle Accidents. HRB Bull. 208, 1959, pp. 16-28.
9. Johnston, J. E. Economic Cost of Traffic Accidents in Relation to Highway Planning. HRB Bull. 263, 1960, pp. 50-53.
10. Smith, R. N., and Tamburri, T. N. Direct Costs of California State Highway Accidents. California Division of Highways, 1967.
11. Motor Vehicle Accident Costs: Washington Metropolitan Area. Wilbur Smith and Associates, 1966.
12. Weisbrod, B. A. Economics of Public Health. Univ. of Pennsylvania Press, Philadelphia, 1961.
13. Weisbrod, B. A. The Valuation of Human Capital. Jour. of Political Economy, Vol. 69, No. 5, 1961.
14. Burke, D. Highway Accident Costs and Rates in Texas. Texas Transportation Institute, 1970.

EVALUATING MUTUALLY EXCLUSIVE INVESTMENT ALTERNATIVES: RATE OF RETURN METHODOLOGY RECONCILED WITH NET PRESENT WORTH

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In both transportation planning and investment analysis literature of recent years an occasional inconsistency has been reported between the results of the rate of return approach and the net present worth approach to the evaluation of mutually exclusive investment alternatives. This paper reviews both approaches to investment analysis and proposes a refinement in the rate of return approach. The refinement involves an examination of incremental cash flows even when the alternatives have equal initial investments and/or differing life spans. The refinement is consistent with the intent of the approach as already described in the literature and yields conclusions that are more often identical to the conclusions that result from application of the net present worth approach.

•THIS paper presents a refinement in contemporary rate of return methodology for the evaluation of mutually exclusive investment alternatives so as to bring about more general consistency between the results achieved by it and the conclusions resulting from application of net present worth methodology. A summary of both approaches is given, followed by a review of examples published since 1966 demonstrating that rate of return and net present worth methodologies can lead to different conclusions regarding the relative attractiveness of mutually exclusive alternatives with identical initial investments and/or different life spans. A procedure is then presented and applied to the examples to do away with the reported inconsistency. The ramifications of situations where there are several rates of return are then discussed.

THE METHODOLOGIES

The procedure for selecting the best of several mutually exclusive alternatives using net present worth methodology is universally recognized as involving a determination of the present worth of the cash or benefit flows for each alternative. All present worth calculations are at the investing institution's minimum attractive rate of return (MARR). The present worths of each of the cash flows for a particular alternative are added together to develop the project's net present worth. The alternative with the algebraically largest net present worth (NPW) is then deemed to be the best of the several mutually exclusive alternatives. Summarizing the foregoing, the best alternative, denoted by a^*, is the alternative for which the following inequality is true for all values of a:

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$$\sum_{t=0}^{n_{a^*}} \left(\frac{1}{1+i}\right)^t A_{a^*,t} \geq \sum_{t=0}^{n_a} \left(\frac{1}{1+i}\right)^t A_{a,t}$$

where

$A_{a,t}$ is the cash or benefit flow for alternative a during time period t ($A_{a,t}$ may be negative),

i is the MARR, and

n_a is the number of time periods involved in the life span for alternative a.

Rate of return methodology for evaluation of mutually exclusive alternatives is somewhat more intricate than the procedure described above. First it is necessary to arrange the alternatives in ascending order of their initial investments. Then the rate of return for each of the alternatives is determined and compared with the minimum attractive rate of return. [Actually it is not necessary to calculate the rate of return for each of the alternatives. If the alternative with the minimum investment has a rate of return in excess of the MARR, all alternatives with larger investments but with rates of return not meeting the MARR criterion will fail to be selected in the analysis of rates of return on incremental investments.] Alternatives whose rates of return are less than the MARR are stricken from the list. The alternative with the smallest investment is then considered as the basis alternative against which the alternative with the next higher investment is compared in order to determine whether the incremental investment and the cash flow following it involve a rate of return in excess of the MARR. If the alternative with the second smallest investment involves an incremental investment whose rate of return is in excess of the MARR, the second alternative replaces the first, and the first is then discarded. Otherwise the second alternative is deleted from the list. In either case the third alternative is then compared with the alternative remaining from the previous comparison in the same manner that the second alternative was compared with the first. The analysis continues iteratively until the list of alternatives is exhausted.

The procedure described in the preceding paragraph essentially follows the procedure described in Grant and Ireson (2, chapter 12) and also in Winfrey (5, chapter 7) for comparing mutually exclusive alternatives using the rate of return approach. It often involves more calculations than does the net present worth approach. Nonetheless the rate of return approach in principle brings the analyst to the same conclusion as the net present worth approach regarding the best of several mutually exclusive investments.

INCONSISTENCIES IN CONCLUSIONS ARISING FROM APPLICATION OF RATE OF RETURN AND NET PRESENT WORTH METHODOLOGIES

Grant and Ireson's statement of the rate of return methodology for evaluation of mutually exclusive investment alternatives is not specifically addressed to situations involving alternatives with differing life spans and/or equal initial investments. With respect to alternatives with differing life spans and different initial investments, there is no reason to suspect that Grant and Ireson intended the incremental analysis to be pursued any differently than as described in the preceding section. Winfrey's approach is very similar to that used by Grant and Ireson. The three authors in their two books also discuss the advisability of generally using a single analysis period for comparing mutually exclusive alternatives with different life spans. Neither of the two books specifically shows how to apply rate of return methodology in the comparison of mutually exclusive alternatives with equal investments. It appears, though, from the methodology's general application that some analysis of incremental cash flows should be made.

A review of several examples published since 1966 to demonstrate that net present worth methodology and rate of return methodology can lead to conflicting conclusions indicates that these examples invariably involve alternatives having identical initial investments and/or different life spans. Furthermore, the conclusion that the two methodologies can lead to inconsistent decisions is generally based on analysis that does not involve reviews of incremental cash flows.

Wohl and Martin in their 1967 Highway Research Board publication (6) as well as in their text published during the same year (7) present three illustrations, each involving two mutually exclusive alternatives and each demonstrating that the net present worth and rate of return methodologies lead to different results. Their first illustration includes two alternatives whose investments are unequal and whose life spans also are unequal. The rate of return for the one alternative is greater than that for the remaining alternative, but the net present worths calculated at the minimum attractive rate of return are in opposite order. Their second illustration involves alternatives with equal investments but different life spans. Again the ordering of the alternatives' rates of return is different from the ordering of their net present worths calculated at the minimum attractive rate of return. Wohl and Martin's third and final example involves two alternatives whose lives are equal and whose investments are equal but whose rates of return are in one order and net present worths are in another. Their third illustration is taken from Bierman and Smidt (1) and will be discussed at greater length later in this paper.

An illustration involving mutually exclusive alternatives is also given by de Neufville and Stafford (3). Their example involves alternatives with equal investments, but the life span for one alternative is one time unit and the life span for the other is two time units. As for each of the three Wohl and Martin examples, the order of the rates of return is opposite to the order of the net present worths.

For each of the illustrations cited above, Wohl and Martin as well as de Neufville and Stafford choose to elect the selections given by application of net present worth methodology. Their rationale is essentially that rate of return methodology implicitly assumes that positive cash flows are immediately invested at an interest rate equal to the rate of return, whereas in fact the positive cash flows are reinvested at the minimum attractive rate of return. There can be no arguing with their selections, for it is generally agreed that the very concept of the minimum attractive rate of return requires that positive cash flows that are reinvested for the long term earn interest at the MARR.

RESOLUTION OF THE INCONSISTENCY

It appears that the basic cause of the inconsistency between conclusions associated with net present worth and rate of return methodologies is essentially that the incremental analysis required by the rate of return methodology has not been completed in illustrations that strive to point out weaknesses in the rate of return methodology.

Bierman and Smidt (1) illustrate the necessity for completing incremental analysis when rate of return methodology is applied. Their illustration involves two alternatives whose net present worths and rates of return suggest different decisions. The cash flow streams are shown in Figure 1 and are respectively labeled Y and Z. [In all the cash flow diagrams shown in this paper the downward pointing arrows indicate cash outlays and the upward pointing arrows indicate cash receipts. In all of these diagrams the abscissa represents time.] With respect to alternatives with identical investments, Bierman and Smidt indicate that such a case seems different from the usual situation in which initial investments are not identical but that "... the difference is superficial" (1, p. 42, 2nd Ed.; p. 41, 3rd Ed.). They go on to determine the incremental cash flow shown in Figure 1 of this paper by the plot for (Y-Z) and then find that the incremental outlay associated with Y relative to Z does indeed produce a rate of return that exceeds the minimum attractive rate of return, although alternative Y has a lower rate of return than does alternative Z. Bierman and Smidt's conclusion then is that alternative Y is the better alternative regardless of whether the selection is made by rate of return methodology or net present worth methodology.

It is unfortunate that Wohl and Martin in both of their 1967 publications did not fully adhere to Bierman and Smidt's suggestions regarding the necessity for analysis of incremental cash flows. If they had done so their conclusions regarding the Bierman and Smidt example in Figure 1 would of course have been consistent with Bierman and Smidt's own conclusions presented in the text adjoining the table in which Bierman and Smidt partially summarize their example. Furthermore, the other two examples presented by Wohl and Martin, when subjected to similar incremental analysis as shown

Figure 1. Comparison of mutually exclusive alternatives Y and Z when minimum attractive rate of return is 5.0 percent [source: Bierman and Smidt (1, p. 42, 2nd Ed.; p. 41, 3rd Ed.); referenced in part: Wohl and Martin (6, pp. 46-48, and 7, pp. 241-243)]. Note: In this and following figures, NPW = net present worth at time zero; R of R = rate of return.

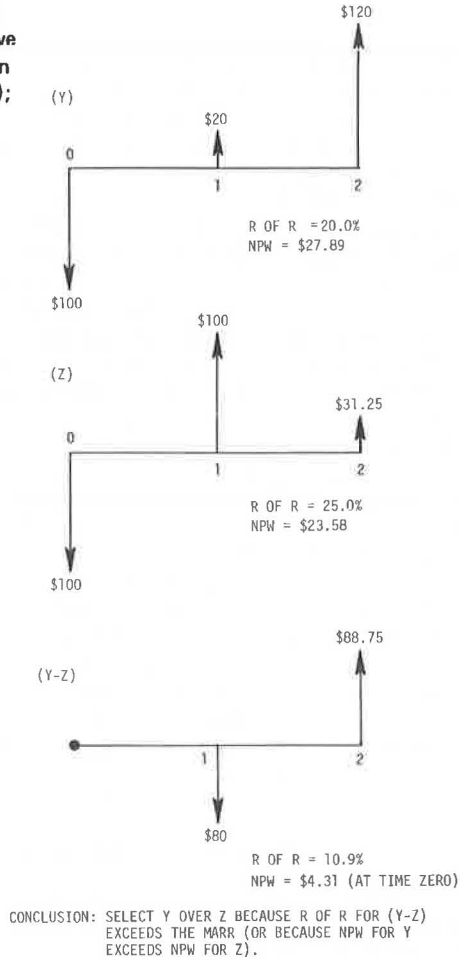


Figure 2. Comparison of mutually exclusive alternatives A and B when minimum attractive rate of return is 6.0 percent [source for cash flows A and B: Wohl and Martin (6, p. 45, and 7, p. 238)].

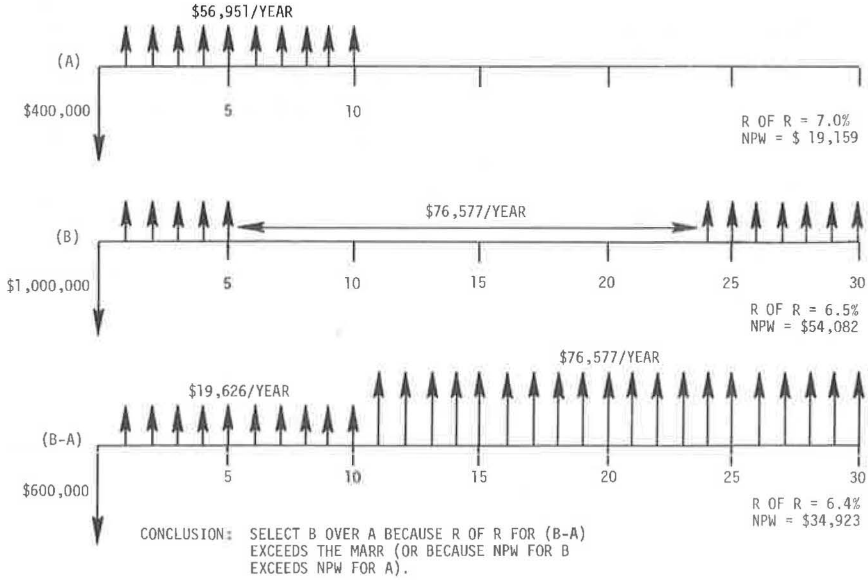


Figure 3. Comparison of mutually exclusive alternatives B and C when minimum attractive rate of return is 6.0 percent [source for cash flows B and C: Wohl and Martin (6, p. 45, and 7, p. 239)].

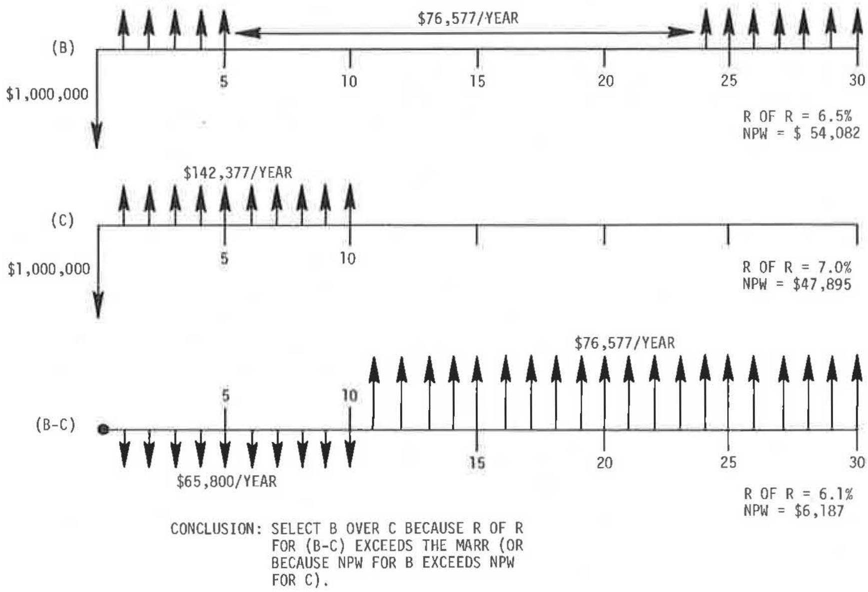
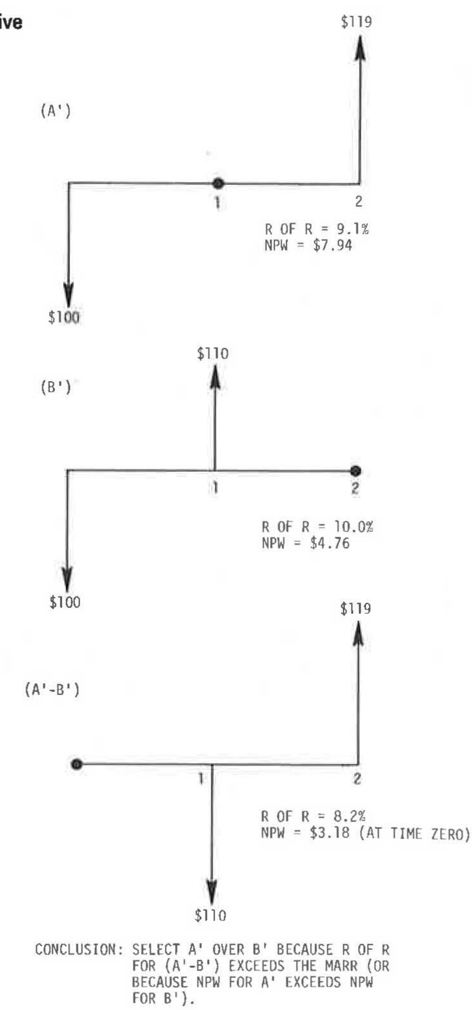


Figure 4. Comparison of mutually exclusive alternatives A′ and B′ when minimum attractive rate of return is 5.0 percent [source for cash flows A′ and B′: de Neufville and Stafford (3, p. 186)].



in Figures 2 and 3, result in conclusions that are totally consistent with those reached using net present worth methodology. The same conclusion can be made with regard to the de Neufville and Stafford example as a result of analysis that is shown in Figure 4.

To conclude then, it must be recognized that analysis of incremental cash flows is mandatory when comparing mutually exclusive alternatives, even when initial investments among alternatives are identical or when project life spans are different. Perhaps this conclusion is slightly more specific than Grant and Ireson's description of rate of return methodology for comparison of mutually exclusive alternatives. Nonetheless it is consistent with their description as well as with Bierman and Smidt's conclusions regarding the example shown in Figure 1. To summarize this conclusion that incremental analysis is mandatory in cases when the initial investments of two alternatives are identical or when their life spans are different, a flow chart has been prepared, shown here as Figure 5. Notice that the second step in this flow chart establishes a procedure for ordering alternatives with identical initial investments and that the fifth step provides a procedure for determining incremental cash flows when the life spans of the two alternatives being compared are not necessarily equal.

MULTIPLE SOLUTIONS FOR THE RATE OF RETURN

Figure 5 emphasizes the necessity of calculating rates of return for each alternative's cash flow as well as each alternative's incremental cash flow over that of the last acceptable alternative. At either stage the analyst will occasionally discover that the solution for the rate of return will not be unique, thus necessitating further work before reaching a decision. The purpose here is not to describe in detail the character of the analysis that is required; rather, it is to recognize the problem and to then point out difficulties in applying both net present worth and rate of return methodology in such cases.

Multiple solutions cannot occur unless there is more than one change in the signs of successive cash flows. For example, for the following cash flow,

Time	Cash Flow
0	-\$100
1	+\$250
2	-\$155

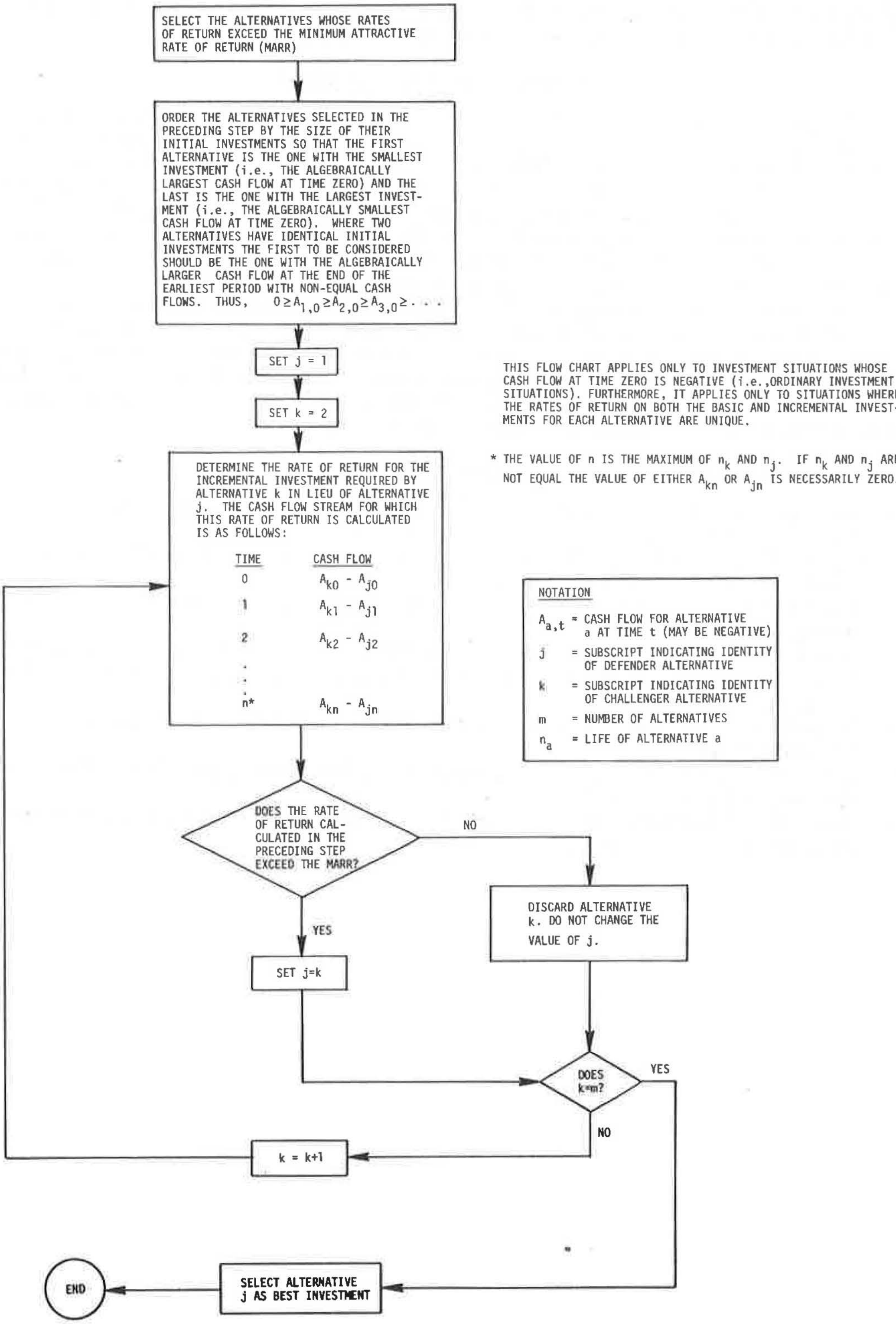
there is a change in sign between the cash flows at times 0 and 1 and again between the cash flows at times 1 and 2, making possible a maximum of two solutions for the rate of return. In this particular case there are two rates of return, whose values are 13.8 percent and 36.2 percent. For all MARR values that are either below 13.8 percent or above 36.2 percent the net present worth is less than zero. But if the MARR is between 13.8 percent and 36.2 percent it will be found to be positive. Consequently an enterprise that ordinarily has a 10 percent MARR can find itself in the curious situation of justifying this project only by increasing its MARR to some rate such as 15 percent or 30 percent. Thus both methodologies are ambiguous for the situation just described.

The resolution of the problem in the case at hand lies in ascertaining the rate of interest that applied to the portion of the funds received at time 1 and that is reinvested to provide for the outlay required at time 2. Often this rate is much less than the MARR and can be as low as the interest rate paid on short-term government securities. If that rate is 0 percent for the situation just described the net cash flow stream becomes

Time	Cash Flow
0	-\$100
1	+\$ 95

and the project has a negative rate of return and a negative net present worth for all positive MARR's.

Figure 5. Rate of return methodology for selecting the best of several mutually exclusive investment alternatives.



There are other ramifications of this problem that can be discussed, but these will not be reviewed here. The interested reader is encouraged to consult references such as Appendix B of Grant and Ireson (2), Chapter 3 of Bierman and Smidt (1), or an interesting paper by Teichroew, Robichek, and Montalbano (4).

SUMMARY AND CONCLUSIONS

The main point of this paper is that incremental cash flows must always be reviewed if rate of return methodology for the analysis of mutually exclusive alternatives is to yield results that are consistent with those resulting from application of net present worth methodology. Several examples that have been published since 1966 to illustrate an inconsistency between the two methodologies have been reviewed and shown to in fact involve consistent conclusions when the rate of return methodology involves review of incremental cash flows. To outline in detail the steps involved in rate of return methodology, a flow chart has been prepared and included as Figure 5.

In closing, it may be appropriate to note that rate of return methodology often involves a larger number of calculations than does net present worth methodology. Consequently no issue is taken here with the viewpoint that net present worth methodology is often simpler to apply in the evaluation of mutually exclusive alternatives than is the rate of return methodology. The only point here is that the two methodologies when properly defined do in fact yield consistent results.

REFERENCES

1. Bierman, H., Jr., and Smidt, S. The Capital Budgeting Decision. Macmillan Co., New York, 1966 (2nd Ed.) and 1971 (3rd Ed.).
2. Grant, E. L., and Ireson, W. G. Principles of Engineering Economy (5th Ed.). Ronald Press Co., New York, 1970.
3. de Neufville, R., and Stafford, J. H. Systems Analysis for Engineers and Managers. McGraw-Hill, New York, 1971.
4. Teichroew, D., Robichek, A. A., and Montalbano, M. An Analysis of Criteria for Investment and Financing Decisions Under Certainty. Management Science, Nov. 1965, pp. 151-179.
5. Winfrey, R. Economic Analysis for Highways. International Textbook Co., Scranton, 1969.
6. Wohl, M., and Martin, B. V. Evaluation of Mutually Exclusive Design Projects. HRB Spec. Rept. 92, 1967.
7. Wohl, M., and Martin, B. V. Traffic System Analysis for Engineers and Planners. McGraw-Hill, New York, 1967.

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