# The Community

## Systems Evaluation: An Approach Based on Community Structure and Values

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This paper presents a procedure for the evaluation of alternative transportation system design concepts based on a comprehensive, weighted hierarchy of community development criteria. Existing techniques for alternative plan evaluation are discussed, along with several potentially powerful normative procedures for system design.

The basic decision model relates to the evaluation of alternative design concepts by a single group of professional planners on the basis of a single set of weighted community decision criteria statements. Extensions of the basic model relating to a possible stratification of statements of value by socioeconomic groups and a possible stratification of planners are indicated. Necessary discussion of community decision structure, formulation of community decision criteria, and weighting of those criteria are summarized.

The decision model procedure is applied to three alternative systems design concepts for the transportation plan in the Louisville metropolitan area. Obvious extensions of the research are identified and applications of the procedures in land-use form and plan analysis, transportation corridor analysis, and detailed transportation system evaluation are discussed.

•ALTHOUGH a great deal of sophistication has been reached in the urban transportation planning process, this same level of sophistication has not been reached in plan evaluation. With regard to this general field of research, certain focal points within the problem area have been isolated. They are (a) criteria for evaluating alternatives, (b) techniques for identifying objectives, and (c) use of models in the design process.

This paper presents a technique for utilizing a weighted hierarchy of community decision criteria, or community goals and objectives, in a systematic evaluation of alternative transportation system design concepts. Heretofore, criteria utilized in plan evaluation have generally been easily quantified economic considerations. An alternative to that approach is considered here which utilizes a broader, more comprehensive class of criteria, including social values along with traditional economic considerations. Applied decision theory is used to establish orderly methods of making comparisons between the various alternative design concepts or philosophies.

A group of professional land-use and transportation planners establish effectiveness values for the design concepts relative to each item in a comprehensive statement of community decision criteria. The decision model utilizes these effectiveness values

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along with utility values associated with each element in the criteria set and proposes for adoption that plan possessing the highest aggregate "plan effectiveness" as defined herein. Various interesting techniques relating to this approach have been published previously and are summarized here. Several proposals for mathematical programming procedures for use in systems design are discussed that may prove useful in eventually structuring a truly optimal approach to system design and evaluation.

The central problem considered in this research is the evaluation of alternative system design concepts by a group of professional planners and engineers on the basis of the probability associated with goal achievement, assuming the adoption of each of the three alternative proposals. Effectiveness values for each alternative with respect to each of the criteria are presented and the rationale associated with the development of these values is given. Detailed presentations relative to community decision structure, statement of community decision criteria, weighting of the elements in a comprehensive hierarchy of community decision criteria, and the statistical analysis of scaling or weighting techniques are beyond the scope of this research; however, results obtained in these areas are summarized insofar as they relate to this paper.

Direct application of these procedures in land-use form analysis, land-use plan evaluation, detailed transportation plan evaluation, and transportation corridor analysis is discussed. Interesting extensions of these procedures in the areas of mathematical programming and more detailed and explicit definition of "yardsticks" for measuring plan effectiveness are presented.

## EXISTING TECHNIQUES

Current research and practice have attempted to present means of evaluating alternative proposals based on impact analysis, benefit cost analysis, and other largely economic approaches. Although these purely economic approaches are not proposed for use in this research, their merits are recognized. This research relates to an approach utilizing elementary decision theory (several models are presented later) based on a comprehensive hierarchy of decision criteria rather than a set of decision criteria limited to economic considerations.

Several interesting schemes for system evaluation are presented, followed by a section relating to normative procedures that may prove to be valuable in system design. The central problem in urban planning is the development of planning proposals that satisfy, to the greatest extent possible, the stated goals and objectives of the community within realistic constraints. Mathematical programming provides a framework within which such optimizing or normative planning procedures may be carried out.

### Alternative Plan Evaluation

Alexander (2) relates the development of a physical form in a manner consistent with the achievement of stated goals. Although the approach is not recognized as a workable, quantitative tool, it sets the framework for the development of a physical form based on the criteria of achievement of stated planning goals.

The theory of design proposed is plan evaluation based on goals. The form is the design solution which fits the problem, called the context. There are a number of variables contained within the context which the form must satisfy; the better the form meets all these variables (criteria), the better the design solution is for that particular problem (context). Each meeting of criteria is called a fit of that form; each lack of meeting is a misfit. For example, the context of an urban freeway has many variables—beauty, economy, neighborhood continuity, capacity, safety, durability, etc. A freeway (the form) is just as good as it meets (fits) these variables. The difficulty arises in adjusting the form until it best fits all the variables of the context at one time. Adjustments of one aspect of the freeway (e. g., economy) to get a better fit may have ramifications in many other aspects (e. g., beauty, safety) causing a lesser fit overall. Thus these are links between the variables in the form, which may be strong or weak, such that altering one causes the alteration of others. These interconnections may be represented by a mathematical graph. If these links can be recognized, and the system as represented by the graph can be broken down into a series of subsystems, alterations of variables within any subsystem set up ramifications along the links, which are dampened between subsystems because of the weak connections between them. Thus the variables of the form can be intelligently altered without the effects spreading in an unknown pattern to all variables. A mathematical formulation is set out to "optimize" this complete system and satisfy all variables at once as best they can be.

It is an interesting concept and may well have direct bearing on plan evaluation, each (with its objectives) being a variable with potential misfit, and the planned solution (form) must be altered intelligently to best satisfy all criteria.

Klein and Meckling (17) present a study of the application of operations research to development decisions. The fundamental approach relates to the selection of courses of action in initial stages of planning, consistent with a wide range of possible desirable alternative developments in effectuation. By this approach, the choice may be narrowed as decisions are made with progressive development. Due to the foresight of the earlier decisions, this development will be consistent with the overall objectives of the program.

The President's Water Resources Council report (21) considers the problem of policies, standards, and procedures associated with the formulation, evaluation, and review of plans for the use and development of water and related land resources. The publication defines general policies for evaluation at a national level and has no direct applicability in this research. Quantitative policies are not established; instead, broader administrative criteria are considered. The work could have some applicability in regional planning of very large regions.

The Southeastern Wisconsin Regional Planning Commission (23) defines planning as a rational process for formulating development goals and objectives. Development objectives should incorporate the combined knowledge of many people who are informed about the planning region and should be established by elected or appointed officials rather than planning technicians. This is a particularly important point because of the value system implications inherent in any set of development objectives. They have provided for the establishment of an advisory committee to assist the commission and its staff in the conduct of a regional planning program. Only by combining the cumulative knowledge and experience the various advisory committee members possess can a desirable future regional development plan be obtained. To be useful in the regional land-use transportation planning process, objectives must be precisely stated and related in a measurable way to alternative physical development proposals. Two basic types of objectives are (a) those that are difficult to relate directly to development plans, and (b) specific development objectives that can be directly related to physical development plans.

The quantification of specific objectives is facilitated by complementing them with planning standards that are in turn directly relatable to planning principles. A point fundamental to the development of this research is that land-use planning objectives cannot be separated from transportation planning objectives.

The specific objectives adopted for the regional transportation plan are those concerned primarily with a balanced transportation system; those which reduce traffic congestion, travel time, and accident exposure; and those which minimize costs and disrupting influences. An overall evaluation of each transportation plan must be made on the basis of the cost. An analysis may show that one or more of the standards cannot be met practically, and must be reduced or eliminated. No plan will meet all of the standards completely. The extent to which each standard is exceeded or violated serves as a measure of the ability of each alternative proposal to achieve specific objectives. Certain objectives or standards may be in conflict, requiring resolutions or compromise, and meaningful plan evaluations can only take place through a comprehensive assessment of each of the alternative plans against all of the standards.

Hill (13) presents a method for the evaluation of transportation plans. He notes that benefit-cost analysis was developed as a technique for examining plans with respect to their achievement of economic objectives. Although lip service is given to intangibles, they do not really enter into the analysis of many transportation and development plans. Urban objectives may have several dimensions—cultural, political, ethical, aesthetic, and economic. To pursue only one dimension would indeed lead to a suboptimal solution. Hill uses a goal-achievement matrix in his analysis and assumes that community objectives have been identified and relative weights attached to these objectives. The next step, therefore, is the comparison of plans in order to determine which plan best realizes the objectives of a community. An important set of requisites is feasibility, immediacy, and interdependence. The importance of being able to predict the reaction of the existing institutional power structure to various planning proposals is emphasized. The sections of the community to which costs and benefits accrue should be identified. In discussing the determination of weights to be associated with the various goals, Hill suggests the consideration of one or more of the following: community decision-makers, the general public by means of general referendum, a selective sampling of the affected groups, community power structure, public hearings, and the investigation of the pattern of previous allocation of public investment. Hill considers the strong effect of transportation on land-use development by noting possible impacts on neighborhoods and use of transportation facilities to separate incompatible land uses.

Thomas and Schofer (24) state that an inflexible commitment to evaluation strategies relying on the quantification of intangibles such as aesthetics would not constitute an optimal solution in plan evaluation. Major transportation decisions should remain in the hands of political decision-makers. Their review of literature resulted in the following:

1. A particular set of problems is perceived and the need for a solution is noted.
2. A preliminary set of criteria for evaluating alternative solutions is developed. These criteria must be available prior to the formulation of alternative solutions, so that a relevant set of alternatives may be devised.
3. Alternatives are generated.
4. Evaluation of alternative solutions is carried out.

When the characteristics of the alternatives are made available to the public, either at the formulation or evaluation stage, formal or informal interest groups are frequently aroused. If an alternative is found politically and technically acceptable, plans to proceed with design and construction are made. If not acceptable all plans may be rejected and, based on the arguments of the various formal and informal interest groups, a revised perception of the problem, the need for solution, and the evaluation criteria evolve. The process would be expected to cycle in an iterative manner until either a solution to the problem is developed or until the perception of the need indicates that the problem is not so serious as to merit the expenditure of resources required for its solution.

The statement of the plan evaluation problem has been structured as follows:

1. Determine the dimension of the transportation problem as it is viewed by the politicians and interested citizen groups.
2. Determine whether there is a finite set of regularly appearing transportation issues, whether new issues have emerged or old issues have disappeared during the past 20 years, and whether the relative importance of various issues has changed over the last 20 years.
3. Determine the scope and range of the issues relative to comprehensive planning goals. Are interest groups single or multipurpose oriented? Do multipurpose oriented groups emphasize one issue to the virtual exclusion of all others at any particular time? To what extent are non-transportation consequences emphasized? To what extent are the interest groups concerned with the intended consequences of the plan and to what extent are they concerned with the unintended consequences?
4. Determine the relation between published reports and public reaction in the form of isolated response and concerted group efforts.
5. Determine the nature of the political power structure with respect to transportation decision. Is the power structure diffused or centralized? Identify the participants in the transportation planning process.
6. Determine the conceptual model that best represents a process whereby an initial perception of social need is transformed into a political decision followed by implementation of a plan to meet that need.

Efforts are being made to develop criteria sets and to evaluate strategies that will be compatible with a complex political environment. Ackoff (1) studied individual preference for various modes of transportation and applied utility theory in the prediction of modal split. He identified factors affecting choice of transportation mode, such as safety, comfort, convenience, travel time, and economy. It is possible to scale or quantify these factors and consistent relationships can be found between personal preference and modal choice. The work, although directly related to the problem of modal split, indicates potential uses of utility theory in plan evaluation.

Lesourne (18) considers the application of operational research in comparing alternative city plans. Comparing city plans takes the form of comparing sets of hypotheses bearing simultaneously on locations of swellings, locations of industrial areas, and the nature of the transportation structure. From the definition of criterial for comparing urban plans two types of studies may be derived: practical research relating to the plan selection and theoretical research relating to the development of an optimal land-use transportation system.

Jessiman et al (16) present a rational decision-making technique for transportation planning, which is stated as follows:

1. Itemize the objectives which the community hopes to achieve in providing the transportation facility.
2. Select the parameter which best measures each objective.
3. Assign a weight or utility value to each of the objectives which reflects a measure of community value.
4. For each objective, examine the parameter chosen as the yardstick of that objective and determine, by use of a scale such as a utility curve, the value for that alternative.
5. For each alternative, sum the values assigned for all objectives to determine the alternative with the highest total value, that is, the one which best satisfies the complete set of objectives.

The planner must consider all effects of each alternative on the overall community system. Difference in points of views must be reconciled. Trade-offs relative to increased operating balance of public transportation and increased congestion must be objectively evaluated in view of an overall goals structure. In developing yardsticks, economic criteria seem to be the only criteria that are effectively considered. The use of utility values as criteria weights is proposed and the concept of marginal utility is presented. The relationship between incremental amounts of certain facilities and utility weights assigned to these incremental amounts may not be a linear relationship. For example, the first mile extension into a corridor may be more desirable than the second. The marginal utility approaches zero beyond a certain length of extension.

Persons familiar with the value systems of the various interest groups in a community may gain insight into reasons for controversies surrounding a project. An investigation of parametric programming or sensitivity analysis of a given solution relative to slight changes in parameters associated with that solution, such as total budget expenditure, is suggested.

Tendencies to emphasize judgment and subjective probabilities are considered a backlash to rapid expansion in the development of precise computer models. Techniques currently used in personnel evaluation by industry may be of value in alternative plan evaluation.

Similar approaches are considered by Irwin (15) in a discussion of criteria for evaluating alternative transportation systems. Transportation planning standards have far-reaching implications involving philosophy, economics, politics, sociology, engineering, and aesthetics. The purpose of Irwin's research is the definition of criteria on which the plan evaluation process may be based. Selection, definition, and application of criteria for evaluating transportation systems contain much uncertainty. More knowledge is urgently needed about the effect of these uncertainties on transportation planning decisions.

Recent developments in allocation theory may be applied to management decision problems. The work of Dean and Nishry (6) relates to scoring and profitability models for evaluating and selecting engineering projects. They consider problems involving the specification and allocation of manpower, funds, and equipment to projects within a firm. Quantitative measures of organizational performance must be derived that are consistent with corporate goals and that consider relevant resource variables, noncontrollable variables, parameters, and constraints. The authors develop mathematical models that yield solutions for allocating manpower resources to projects. The allocation procedure could be used in the selection of alternative community development plans and in the allocation of public revenues to development proposals.

Pessemier (20) develops a system wherein benefits may be measured in a dollar metric by a prescribed method of making trade-offs between various proposals and the "do nothing" alternative. The procedures require accurate cost data so that intangible or total benefits may be quantified. Although an application of Pessemier's procedures has not been attempted here, such application may greatly strengthen conventional benefit-cost techniques.

Hemmens (12) presents experiments in urban form and structure and states that the evaluation of alternative land development patterns is an important, unsolved task in urban planning. There are many reasons for slow progress in developing methods for evaluating alternative development plans. Among these reasons is disagreement about the proper criteria for evaluation. The solution to a part of this problem may be found in the development of a fairly simple experimental model of an urban community; a model designed specifically for the exploration of the relationships among elements in urban form. The paper is a progress report on a simple model for examining the impact of changes in components of urban form on urban spatial structure.

A distinction is made between urban form and urban structure. Urban form is the physical arrangement of residents, work places, etc. Urban structure is the pattern formed by the connection of these elements in the daily activities of areas of residents.

The author uses a simple linear programming formulation for evaluating urban form on the basis of two criteria: the efficiency of each alternative in terms of minimum travel requirement, and the equity of the alternatives in terms of locational advantage of residential locations. Given alternative distributions of work places, shopping places, residences, and systems of transportation service, and given an allocation rule specifying the manner in which residences will be linked with work places and shopping centers, determine the nature of change in urban form and urban spatial structure. The report examines the relationships among elements of form as a first step toward developing more satisfactory analytical methods of evaluating alternatives.

Dansereau (4) presents an evaluative scheme based on attitudes and economic climate as they affect highway development. The work predicts economic development at selected interchanges, develops alternative land-use plans for interchange protection, and identifies factors conducive to community adoption of reasonable protective regulations. Citizen acceptance of local highway changes is related to acceptance of rational controls and ultimately to implementation of necessary protective practices.

Three types of attitude studies were undertaken: (a) study of attitudes towards local highway developments, (b) study of attitudes toward planning and zoning practices, and (c) study of attitude change toward both development and control practices. Economic considerations that have influenced the findings of the attitude research were studied. The economic analyses consisted of study of land use and land value, study of predictions of interchange development, and study of the economic impact of the interchange development.

Worrall (26) presents an interesting discussion of the use of an urban panel as a longitudinal data source for urban planning. The paper treats data collection as it relates to plan evaluation. Modeling technology is constrained by the characteristics of existing data systems. Data formats developed prior to the current focus on model-building activity are inadequate for present purposes. Present data formats specify an initial level of aggregation considerably in excess of that desired by the analyst. They are predominantly cross-sectional rather than longitudinal in form, and the information content is such that it seldom permits a full-scale evaluation of policy impact.

The paper considers the feasibility of developing a new form of data system for continuous recording of urban information. The mechanism employed is that of a permanent household response panel, an approach frequently used in consumer and market research.

The system has applications as a source of data for future model building and as a general mechanism for urban analysis. The paper emphasizes the application of panel techniques in the study of urban travel. The emphasis is one of convenience, reflecting the particular interest of the author. The discussion might well have been centered on the use of panel techniques for the study of residential location preferences, household activity patterns, or others.

## Extremal Methods (Linear Programming): An Optimizing Approach

Hay et al (11) present an interesting use of extremal methods (mathematical programming) in the development of an optimal bimodal transportation system.

A research proposal developed in upstate New York (19) proposes an interesting use of integer programming in the design of a transportation system. The proposal is concerned with the use of operations research (mathematical programming techniques) in the determination of optimal routes and headways for a fixed investment in transit vehicles and/or a fixed level of operating expenditure. The procedure involves the allocation of transit service to existing or proposed route sections in an optimal manner, subject to systems and subsystem constraints. Typical elements of the constraint set are (a) upper limit of available transit system components, (b) lower limit of available transit system components, (c) upper limit on level of transit service on a specific route, and (d) lower limit of transit service on a specific route. Constraints (c) and (d) are considered to be subsystem constraints.

Optimal design techniques could be applied in determining the optimal expansion of an existing system as well as in determining the best overall design of a new system. The optimal design procedure could serve as a highly efficient method for evaluating changes in stated government policy subject to appropriate constraints. Changes in governmental policy could take the form of variations in the parametric values associated with the mathematical programming formulation of the problem. Such variation could be thoroughly evaluated by well-developed and easily manageable sensitivity analysis procedures.

The New York Office of Transportation plans to conduct the research in three phases: (a) an intensive study of transit usage as it is related to transit service and traffic market potential; (b) the development of the mathematical processes necessary to formulate the allocation; and (c) use of the technique in the planning and design of new systems. The transit revenue function, the function to be optimized, will be an expression of the relationship between transit usage and level of service on specified route sections. Level of service is a measure of passenger-carrying capability and is expressed in some unit of capacity per hour. It is assumed that usage-service relationships would differ in areas of different socioeconomic characteristics. The transit usage analysis would develop a temporal usage rate for each service level for each specific route section.

The significance of sensitivity analysis is pointed out. It will be possible to investigate the effect on the "optimal" allocation of service of variations in the usage-service relationships. The formulation must consider the cost of unused equipment and personnel during off-peak periods of demand.

The New York proposal concludes by (a) restating the obvious desirability of "optimal" transportation systems design, and (b) pointing out that only recently have transportation planners acquired, through phenomenal advances in mathematical programming and computer technology, the capability for undertaking such comprehensive transportation systems analyses.

Hitch (14) discusses the problem of sub-optimization. Comments from his article are repeated here because sub-optimization is taking place in many phases of the planning process. Calculating quantitative solutions based on wrong criteria is equivalent to answering the wrong question. The basis for "good" criteria at any level of analysis in operations research is consistency with "good" criteria at a higher level.

Ridley (22) describes an investment policy to reduce the travel time in a transportation network. A transportation network should satisfy traffic demands placed on it and give service to users on the basis of some acceptable criteria, within budgetary, political, and social constraints.

The transportation network is represented by an abstract graph of nodes and arcs on which are defined real-valued variables and functions representing travel times, traffic flows, and money invested. The travel time on an arc is a known function of investment and the assignment of traffic flow on a particular route varies with the travel time on the arcs. Ridley seeks an optimal set of arcs so that investment in these arcs gives minimum travel time. He presents a combinatorial analysis of the transportation planning process. A lemma is proved which puts upper and lower bounds on the minimum travel time in a network for an investment, M. This is then used in a constructive proof of an algorithm which obtains an optimal set of investments for a given budget.

## ESTABLISHING A WEIGHTED HIERARCHY OF COMMUNITY DECISION CRITERIA

This section is presented to indicate how a set of community goals and objectives could be formulated and weighted. The weighted community decision criteria are essential to the proposed method of plan evaluation emphasized in this paper. The method proposed assumes involvement of community decision-makers in structuring a list of specific community decision criteria. Professional planners would use the decision criteria, weighted by the decision-makers, in the evaluation of planning proposals. The central problem in this research is the development of analytical methods for plan evaluation, having as input to this evaluation a set of weighted community goals and objectives.

Since the plans to be evaluated were for metropolitan Louisville, a task force from the Louisville Mayor's Citizens Advisory Committee was used as the criteria evaluation or community decision-making group. The task force represented a cross section of highly respected, influential citizens of metropolitan Louisville (the area used as the experimental laboratory). This group is interested in and familiar with the area's community goals and objectives.

Although it was convenient and entirely satisfactory in this research to utilize the committee for criteria weighting, a more general criterion for the selection of such a committee may be stated as follows:

> The committee should consist of direct and indirect influentials including popular public officials and representatives of commerce and industry who are influential in controlling development decisions, and those indirect influentials who, by reason of their personal stature and demonstrated interest, are effective in shaping policy on important community issues.

An alternative presentation of this criterion is the following block diagram:

COMPOSITION OF CRITERIA FORMULATION COMMITTEE

| | Influentials | |
|---|---|---|
| | Possible Direct | Actual Indirect |
| Representors | A | C |
| Implementors | B | D |

where the letters are defined as

- A—popularly elected officials;
- B—other heads of public and semi-public bodies, executives of commercial and industrial firms;
- C—unbiased, interested citizens;
- D—other indirect influentials including groups A and B acting outside the area of their direct control.

Procedures used in the establishment of a weighted set of community decision criteria (i.e., specific statements of community goals and objectives) are as follows:

1. Professional planners established a tentative set of community goals and objectives, explicitly and concisely stated.

2. The criteria evaluation group met for general discussion and modification of each item in the statements of community goals and objectives. The end product was a complete statement of community goals and objectives, modified in view of the comments and opinions of the decision-makers or criteria evaluation group. The resulting statements of community goals and objectives are shown in Appendix A.

3. Each member of the criteria evaluation group was asked to individually weight the various sets of criteria by the ranking and rating methods of Appendix B.

4. The decision-makers or criteria evaluation group met and were asked to re-evaluate their initial weighting of the elements of the criteria statements. No committee members changed their initial values.

The aggregated weightings thus obtained, as given in Appendix C, were used in the plan evaluation decision model.

For the two techniques used, the following statistical results were obtained:

1. A high level of agreement among judges using the scaling techniques was observed.

2. Criteria weights obtained by the methods applied were highly correlated in both rank order and interval-level measure. Criteria weights obtained by any given method were highly correlated with criteria weights obtained by averaging all methods.

3. Each judge demonstrated transitivity of preference throughout all methods used.

## PLAN EVALUATION: THE DECISION MODEL

Two similar approaches to the development of a decision model used in alternative plan evaluation are the effectiveness matrix approach and a scoring model. This section will develop the mathematics associated with these techniques and will present an actual application of the effectiveness matrix approach. The scoring model extends the effectiveness matrix technique by treating a stratification of judges by background and interest groupings.

### The Effectiveness Matrix Technique

At this point, it is assumed that a hierarchy of community planning goals and objectives has been established and that a numerical utility measure or criterion weight has been assigned to each objective statement. Three alternative community plans are under consideration. Outlined in this section is a procedure for evaluating the three alternative proposals.

Definition of Terms—Consider here the set of community planning objectives $G_j$ where $j = 1, 2, \ldots, n$, n being the total number of decision criteria under consideration. Second, three plans are proposed for evaluation. The set of plans under consideration is designated by $P_i$, where $i = 1, 2, 3$. Associated with each community planning objective $G_j$ is a numerical utility value $u_j$ $(j = 1, 2, \ldots, n)$ which was determined by the procedures of Appendix B. Regardless of the system of decision criteria under consideration, the following equality must hold:

$$\sum_{j=1}^{n} u_j = 1$$

The purpose of this discussion is to describe a procedure for objectively utilizing weighted community decision criteria in the evaluation of physical development plans; therefore, "effectiveness" ($e_{ij}$) and "plan utility" $U_i$ are defined. Effectiveness ($e_{ij}$) is a measure of the probability that objective j can be achieved if plan i is adopted. $U_i$ is a measure of the total utility of plan i based on the evaluation of plan i relative to all objectives.

The Effectiveness Matrix—The effectiveness matrix was developed by a committee of planners representing the professional disciplines associated with the comprehensive planning process. The effectiveness value ($e_{ij}$) is assigned on the basis that an $e_{ij}$ of

1.0 implies that achievement of objective j is assured under plan i, and an $e_{ij}$ of 0.0 implies that achievement of goal j under plan i is practically impossible. If all plans i have no effect on the achievement or prevention of objective j then all $e_{ij}$ associated with that objective are undefined and the unrelated criterion will be dropped from the effectiveness matrix. Values of $e_{ij}$ will be estimated to the nearest tenth by each evaluator, using the previously defined guidelines. Elements of the final effectiveness matrix ($e_{ij}$) will be documented later in this section with a statement of reason for the numerical value given. In general terms, the effectiveness matrix will have the following form:

EFFECTIVENESS MATRIX

| Alternative Plan | Criterion | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $G_1$ | $G_2$ | $G_3$ | ... | $G_j$ | ... | $G_n$ |
| $P_1$ | $e_{11}$ | $e_{12}$ | $e_{13}$ | ... | $e_{1j}$ | ... | $e_{1n}$ |
| $P_2$ | $e_{21}$ | $e_{22}$ | $e_{23}$ | ... | $e_{2j}$ | ... | $e_{2n}$ |
| $P_3$ | $e_{31}$ | $e_{32}$ | $e_{33}$ | ... | $e_{3j}$ | ... | $e_{3n}$ |
| . | . | . | . | | . | | . |
| . | . | . | . | | . | | . |
| . | . | . | . | | . | | . |
| $P_i$ | $e_{i1}$ | $e_{i2}$ | $e_{i3}$ | ... | $e_{ij}$ | ... | $e_{in}$ |
| . | . | . | . | | . | | . |
| . | . | . | . | | . | | . |
| . | . | . | . | | . | | . |
| $P_m$ | $e_{m1}$ | $e_{m2}$ | $e_{m3}$ | | $e_{mj}$ | | $e_{mn}$ |

In generalized vector notation, the effectiveness matrix may be represented by E.

The Decision Model—A decision model that determines a total effectiveness for each of the plans $P_i$ (i = 1, 2, 3) with respect to the given decision criteria structure $G_j$ (j = 1, 2, 3, 4, 5) follows. For each plan (i), the total utility is the sum of the products of the individual numerical utility of the plan with respect to objective j ($e_{ij}$). The model is mathematically stated as follows:

$$U_i = \sum_{j=1}^{n} e_{ij} u_j \quad (i = 1, 2, \ldots, m)$$

where

$U_i$ = total utility associated with plan i,
$e_{ij}$ = probability that objective j can be achieved if plan i is adopted, and
$u_j$ = numerical measurement of utility associated with community planning objective j.

In the generalized vector notation, the decision model may be stated as follows:

$$\begin{bmatrix} e_{11} & e_{12} & e_{13} \dots & e_{1j} \dots & e_{1n} \\ e_{21} & e_{22} & e_{23} \dots & e_{2j} \dots & e_{2n} \\ e_{31} & e_{32} & e_{33} \dots & e_{3j} \dots & e_{3n} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ e_{i1} & e_{i2} & e_{i3} \dots & e_{ij} \dots & e_{in} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ e_{m1} & e_{m2} & e_{m3} & e_{mj} & e_{mn} \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ \cdot \\ \cdot \\ \cdot \\ u_j \\ \cdot \\ \cdot \\ \cdot \\ u_n \end{bmatrix} = \begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ \cdot \\ \cdot \\ \cdot \\ U_i \\ \cdot \\ \cdot \\ \cdot \\ U_m \end{bmatrix}$$

Or, this can be stated as:

$$U = Eu$$

where $u = (u_1, u_2, u_3, \dots, u_j, \dots, u_n)^T$ is a column vector whose components represent the utility values associated with each of the n community decision criteria, and $U = (U_1, U_2, \dots, U_i, \dots, U_m)^T$ is a column vector whose components represent the plan utility associated with each of the m alternative development plans, and E is the $m \times n$ matrix defined earlier.

The plan possessing the highest total utility would be the alternative plan recommended to the community decision-makers for formal adoption.

## A Scoring Model

Work in the area of development of scoring and profitability models for evaluating engineering projects within an industrial firm presents results that may be applicable in alternative plan evaluation (6). A suggested application is presented here.

Previous definitions of $G_j$, $u_j$, $e_{ij}$, and $U_i$ apply here. At this point the scoring concept is exactly the same as the effective matrix technique described earlier. Consider a panel of judges or community decision-makers, individually representative of different and definable socioeconomic sectors of the community. Vogt (25) and others have indicated that community decisions should reflect the makeup of the community relative to socioeconomic group stratification. The model presented previously could be modified as follows:

$$U_i = U_i^1 + U_i^2 + \dots + U_i^k + \dots U_i^p$$

$$U_i^k = a_k \sum_{j=1}^{n} u_j^k \, e_{ij}^k$$

where

$U_i$ = total score for alternative plan i;

$U_i^k$ = score for alternative plan i as determined by the k th socioeconomic group (k = 1, 2, . . ., p);

$u_j^k$ = criterion weight for objective j as determined by the k th socioeconomic group;

$e_{ij}^k$ = value of plan i relative to the criterion j as determined by the k th socioeconomic group; and

$a_k$ = fraction of the area population represented by the k th socioeconomic group.

As a minor but logical modification of this scoring model, one may consider the development of utility values by different socioeconomic groups of citizens while considering only one set of effectiveness values established by one group of professional planners. This problem may be formulated as the following matrix multiplication:

$$\begin{bmatrix} e_{11} & e_{12} & e_{13} \dots & e_{1j} \dots & e_{1n} \\ e_{21} & e_{22} & e_{23} \dots & e_{2j} \dots & e_{2n} \\ e_{31} & e_{32} & e_{33} \dots & e_{3j} \dots & e_{3n} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ e_{i1} & e_{i2} & e_{i3} \dots & e_{ij} \dots & e_{in} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ e_{m1} & e_{m2} & e_{m3} \dots & e_{mj} \dots & e_{mn} \end{bmatrix} \begin{bmatrix} a_1 u_1^1 & a_2 u_1^2 & a_3 u_1^3 \\ a_1 u_2^1 & a_2 u_2^2 & a_3 u_2^3 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ a_1 u_j^1 & a_2 u_j^2 & a_3 u_j^3 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ a_1 u_n^1 & a_2 u_n^2 & a_3 u_n^3 \end{bmatrix} =$$

$$\begin{bmatrix} U_1^1 & U_1^2 & U_1^3 \\ U_2^1 & U_2^2 & U_2^3 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ U_i^1 & U_i^2 & U_i^3 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ U_m^1 & U_m^2 & U_m^3 \end{bmatrix}$$

Or,

$$Eu = U$$

where

$E = (e_{ij})$ is a m × n matrix. The typical element represents the probability that goal j will be achieved if alternative plan i is adopted.

$u = a_k u_j^k$ is a n × 3 matrix. The typical element represents the utility value (criterion weight) for criterion j as determined by socioeconomic group k. In this example 3 socioeconomic groups are considered; $a_k$ is the fraction of the area population represented by socioeconomic group k.

$U = (U_i^k)$ is a m × k matrix. The typical element represents the aggregate utility (score) assigned to alternative plan i by socioeconomic group k.

By summing $U_{ik}$ value for each row (i) of the U matrix, a utility value (score) for each alternative plan (i) may be obtained. The values will be weighted in a manner consistent with the socioeconomic group composition of the community.

## Model Application and Presentation of Results

The effectiveness matrix technique for plan evaluation has been applied and the results are presented here. The model is described in vector notation U = Eu. The transposed effectiveness matrix $E^T$ is given in Appendix D. The columns represent the 3 alternative plans evaluated and the rows of the matrix represent the 35 criterion statements or community planning objectives. Two professional planners from The Falls of the Ohio Metropolitan Council of Governments (the regional planning authority for the Louisville metropolitan area) and three professional transportation planners from the Louisville Metropolitan Comprehensive Transportation and Development Program participated in the plan evaluation process. The $e_{ij}$ values of Appendix D represent the consensus of this group of professionals.

The components of the column vector u are the utility values associated with the 35 decision criteria or community objectives. This vector is given in Appendix C in the column headed Average Values, $u_j$. As stated earlier, the Task Force 5 values were used in the plan evaluation model because this group formulated the statements of goals and specific objectives and was, therefore, more familiar with the criteria as well as the community involved. Note that the vector u is a 35-component column vector.

The 3 × 35 matrix E was multiplied by the 35 × 1 column vector u to produce a 3 × 1 vector U. That vector is stated as follows:

$$U = (U_1, U_2, U_3)^T$$

or

$$U = (0.38, 0.52, 0.60)^T$$

where each of the values $U_i$ represent the aggregate planned utility associated with each of the three alternative development plans.

Because these plans are transportation system design concepts only, they have not been developed in sufficient detail to provide cost estimates. This precluded the possibility of doing a complete cost-effectiveness analysis.

The aggregate results indicate that the least preferred alternative is plan 1 (Appendix E). That plan is based on extensive improvements of existing at-grade arterial facilities. The second proposed alternative design concept, plan 2 (Appendix F) is based on extensive construction of freeway facilities with no rail mass transit. Plan 2 possesses an aggregate utility approximately 37 percent higher than that possessed by alternative design concept 1. Finally, the most preferred alternative is plan 3 (Appendix G), based on a balance of new freeway construction and rail mass transit. The rail mass transit-oriented alternative possesses an aggregate plan utility 58 percent higher than that of the first design alternative and 15 percent higher than the freeway-oriented design concept.

In the remainder of this section the reasoning involved in the determination of various $e_{ij}$ values is discussed and "yardsticks" for use in determining the respective effectiveness values are identified. The objective statements are shown as quotations and appropriate comments follow.

"Insure safe public facilities." The transit-oriented system was judged most effective in assuring safety, with the freeway alternative second. A yardstick for the measure of effectiveness here may be a study of accident records on various types of transportation facilities, particularly the study of such accident records on facilities in the metropolitan area.

"Provide for adequate public safety regulations and their enforcement." The high effectiveness for plan 2 indicated that the experts felt enforcement of freeways was by far the easiest type of enforcement. Numerous accident or friction points exist in plan 1, while significant policing problems in transit vehicles and stations exist with plan 3.

"Provide for the removal of contaminants (solid, liquid, and gaseous)." The transit-oriented alternative was most preferred here because of the fact that it removes many vehicle miles of travel from the surface street system, thereby reducing air pollution caused by vehicular exhaust. A yardstick to be used in a measurement of effectiveness here may be aggregate vehicle miles of travel. This statistic is highest on a surface street-oriented alternative (plan 1) and, therefore, that alternative is the least desirable.

"Minimize maintenance costs of public facilities." Wide rights-of-way make the freeway alternative less desirable than the surface street alternative; however, maintenance would be most expensive in a transit-oriented system. A yardstick in determining this effectiveness could be the development of maintenance cost records by type of facility.

"Insure maximum effectiveness of public utilities (including transportation facilities) by design and locational considerations." The freeway-oriented alternative was most desirable in this case, furnishing good access to many major public facilities. The inflexibility of mass transit is reflected in the lower effectiveness value of plan 3. Aggregate hours of travel could be a yardstick relative to this objective as well as the accessibility index produced as a part of the standard trip analysis procedures.

"Develop a balanced, effective, and integrated transportation system which provides for the accessibility requirements of each land use." Balance is implied by transit orientation in transportation system development and this implication is reflected in the high effectiveness value of plan 3. The surface street concept is the least effective of these three plans. Yardsticks may be developed in this area, such as analysis of travel by various modes, measurements of delays and frequency of service, and determination of aggregate travel time and aggregate travel costs.

"Develop public improvement programs within available financial resources." Here, plan 1 and the freeway-oriented plan have the highest effectiveness values. The low effectiveness value associated with the mass transit concept reflects the customary subsidy associated with that type of program. The existence of a financing system, such as the highway trust fund based on road user taxes, reflects a system development within available financing.

"Maintain highest equitable property values." Studies have indicated a skyrocketing of property values in freeway and mass transit corridors; however, accessibility by any means seems to enhance property values. The effectiveness values reflect this greater activity in transit corridors.

"Insure effective utilization of mineral, vegetation, air, and water resources." In the opinion of the professionals developing the effectiveness matrix, this objective is not related to or affected by transportation system design concepts.

"Establish a strong economic base through commerce that will bring money into the community." The effectiveness values indicate that a transit-oriented system is stronger relative to inducing a new industry into a community. A freeway-oriented system providing access to suburban areas for industrial park and new plant development was the second preferred, while the alternative based on improvement of existing facilities received a low value for this objective.

"Establish trade development that provides maximum convenience to consumers." The effectiveness values indicate an edge for a transit-oriented alternative over a freeway-oriented alternative with the improvement of existing street concept receiving a somewhat lower value. Although improvement of existing streets provides for more convenience to neighborhood shopping centers, possibly it impedes access to regional and central business district type facilities.

"Insure the optimal utilization of all land." Again, the transit-oriented alternative received an edge reflecting that this system, a transit-freeway system, provides the best access to land in an urban area. The freeway-only alternative was second and the improvement of existing street facilities was the least preferred or the least effective alternative.

"Achieve increased disposable income for all people." Due to the greater accessibility to work locations for all of the population, the mass transit alternative possessed the highest effectiveness value. Again, for reasons of overall accessibility, the freeway-oriented alternative was second. The planners felt that a street system would not provide access to job centers, particularly for that element of the population that could not afford to maintain an automobile.

"Preserve historic sites and areas of natural beauty." Although plan 1 requires less new right-of-way, it was felt that it was the least desirable alternative because it would result in overloaded conditions or street facilities serving historic sites and sites of natural beauty. Proper alignment of a mass transit line could provide mass access to these facilities, thereby resulting in that alternative's receiving the highest effectiveness value.

"Promote adequate public libraries, museums, and cultural activities." Again, the greater overall accessibility provided by a transit-oriented system resulted in that system's receiving the highest effectiveness value.

"Protect meaningful local tradition and encourage civic pride." The greater accessibility of the freeway-only and transit-freeway alternatives results in the high effectiveness for these two plans. The professional planners felt that civic pride is encouraged by a good transportation system, another reason for the high effectiveness values of plans 2 and 3.

"Establish the mechanism for adequate preventive and remedial health programs and facilities." This objective is not related to or affected by transportation system design concepts.

"Develop educational facilities and opportunities for citizens at every level." Again, the high accessibility provided by a mass transit system resulted in that system's receiving the highest effectiveness value. The second highest value is possessed by the freeway-oriented system, with a very low effectiveness value assigned to plan 1, which would not provide good access to high school and higher education activities and facilities.

"Eliminate injustice based on discrimination." In this case, the more accessible systems, plans 3 and 2 respectively, receive the lowest effectiveness values. The planners reasoned that this type development encouraged the development of ghettos for impoverished minority groups.

"Develop needed public welfare programs." The planners indicated that this objective was unrelated to transportation system development.

"Encourage development of religious opportunities." Again, the high accessibility systems as depicted in plans 3 and 2 respectively received the highest effectiveness values.

"Develop an aesthetically pleasing environment." Although this objective is mostly sensitive to urban design concepts, the panel felt that by placing mass transit systems in subways in congested areas, aesthetics could be realized more readily. Also, heavy travel on surface streets was judged not to be consistent with pleasing aesthetic values.

"Establish open-space programs." Concentration of traffic on rail or on limited-access freeways was judged to be most consistent with the establishment on open-space programs.

"Provide adequate recreational facilities utilizing parks, rivers, and lakes." A surface system was judged to provide the greater accessibility to the type of recreation described in this objective. The inflexibility of the mass transit system resulted in its receiving a low effectiveness value.

"Improve the framework (channels, systematic use) for citizen participation in governmental functions." This objective is unrelated to transportation sytem development.

"Establish equitable taxation policies (bases, mixes, rates)." This objective should be applied in transportation system analysis to assure that equitable cost-sharing is established between users and nonusers and to assure that transportation facility development costs are equitably distributed between participating agencies charged with the responsibility for developing these facilities. The low effectiveness value for the mass transit system indicated that the subsidy normally associated with this type system development is a taxation inequity.

"Achieve efficient governmental administration, representative of all citizens." This objective is not related to transportation system development.

"Develop adequate government staffs and personnel programs (high job standards, reasonable salary ranges, effective delegation of authority)." This objective is not related to transportation system development.

"Establish sound governmental fiscal programs." Again, the subsidy normally associated with mass transportation is regarded as not a sound fiscal program.

"Develop an effective, long-range, metropolitan-wide planning process." This objective implies that transportation and development policies must be coordinated and that studies of both lead to the development of a planning process and implementation devices which accomplish the goals for the least expenditure of direct and indirect costs. The development of an integrated system as reflected in plan 3 seems to be most consistent with this objective.

"Establish effective control mechanisms." This objective is unrelated to transportation system development.

"Encourage rehabilitation and conservation neighborhood programs." The low effectiveness of the transit-oriented alternative implies that many neighborhoods cannot be effectively served by an isolated transportation system such as a mass transit system. The development of a street system coordinated with urban redevelopment projects is an obvious technique implied in the implementation of this objective.

"Provide adequate low-cost housing." The transit-oriented alternative received the highest effectiveness value because the planners establishing these values felt that low-cost, high-density housing could be served best by a transit-oriented transportation system.

"Develop neighborhood units." The surface street system providing good transportation access to neighborhoods was judged to be most effective. A yardstick to be used in a measurement of the compliance of various plans with this objective could be the measurement of vehicle-pedestrian conflicts at the neighborhood level and the measurement of through traffic within neighborhoods.

"Promote a wide variety of housing types as required within the community." The high effectiveness for plan 3 reflects the planner's opinion that rail mass transit could serve high-density residential corridors and promote most effectively the wide variety of housing mentioned in this objective.

As will be stated in the next section, the area of developing yardsticks for measuring the extent to which a plan is compatible with the various objectives presents a most challenging area of further research. This section has provided some examples or guidelines for the development of quantitative and effective yardsticks, along with comments concerning the thinking of the professionals in arriving at the effectiveness values.

## SUGGESTED FURTHER APPLICATIONS AND EXTENSIONS

It is anticipated that continuing application and refinement of these techniques will be made a regular part of the Work Program of the Louisville Metropolitan Comprehensive Transportation and Development Program. Obvious applications of the techniques to the work in Louisville are (a) for improvement of the existing recommended plan, (b) for use in the evaluation of alternative land-use forms now under consideration by development planning agencies, and (c) for use in the analysis of selected transportation corridors.

### Improvement of Selected Plan

The study consultant will recommend a transportation plan to the Transportation and Development Program. It is proposed that the plan evaluating schemes of this research be applied to that selected plan in a diagnostic manner. The recommended plan will be analyzed in detail relative to each of the community objectives in the weighted hierarchy of community goals and objectives given in Appendix C. On the basis of this evaluation, an analysis of the recommended plan can be made. In the areas where the plan is weak with respect to certain goals and objectives, action to remedy such shortcomings in the plan will be considered.

Currently, a study by The Falls of the Ohio Metropolitan Council of Governments is concerned with the development of a more complete set of community goals and objectives. The goals and objectives study will be carried out over the next two years and will result in a more comprehensive statement of goals and objectives than presented here. At that time, the scheme for evaluation will be repeated subsequent to the weighting of the decision criteria. Again, modifications of the transportation plan will be considered on the basis of the results of the study.

## Alternative Land-Use Forms

The current transportation planning program in the Louisville metropolitan area has been based on a single land-use form, defined by the Louisville and Jefferson County Planning Commission as "planned sprawl." Other fundamental land-use forms such as satellite cities, radial corridors, and others are being considered by the development agencies of the area. When a comprehensive plan based on an alternative land-use form is available, a more extensive application of these procedures will be possible. At that time, the procedures may be used to evaluate the alternative land-use forms, the alternative transportation plans associated with these forms, and, finally, alternative comprehensive development plans that encompass both land use and transportation.

## Corridor Analysis: Route Planning Studies

In addition to the recommendations relative to new freeway systems and new arterial systems for a metropolitan area, a large effort of the continuing planning process relates to the improvement of existing facilities within that area.

One of the significant tasks associated with this improvement of existing facilities is corridor analysis or route planning studies. It is anticipated that the techniques of this research will be most useful in the development of plans associated with the improvement of existing facilities. Alternative routes may be considered and each of these alternatives may be evaluated in the context of the community goals and objectives structure presented.

An immediate suggestion relative to the application of these techniques in route planning is the development of a pilot study or set of guidelines for the application of these techniques to the planning analysis of an individual corridor instead of a total transportation system.

## Defining the Decision Variables: A Work Program Reflecting Specific Objectives

The earlier sections of this research have presented an approach to plan evaluation based on a weighted hierarchy of community decision criteria or goals and objectives. Hopefully, the procedures resulting from this research presented in the earlier sections will provide planners with a straightforward, efficient, and effective methodology for weighting goals and objectives and evaluating alternative plans. It is recognized, however, that the techniques proposed are suboptimal in many respects. Many "givens" are imposed upon the process. Planning is treated as a "second-order" governmental function below the policy-making and financing processes. Possibly, if decisions at the primary level could be guided quantitatively by the weighted hierarchy of community goals and objectives, a truly optimal approach would exist.

Studies of suboptimization (14) indicate that "good" decision criteria at any level are consistent with "good" decision criteria at higher levels. Quantitative solutions based on the wrong criteria (in this case "wrong" givens input to the planning process) are tantamount to answering the wrong question, and this may well apply to the community development process. With most metropolitan governments, well-defined criteria do not exist at the higher level, and this results in suboptimal lower level planning decisions.

This section proposes a procedure for top-level community decision-making using cardinal utility values in an optimal allocation of community resources.

One may consider the mapping of a closed, precisely defined set of community values onto a set of community goals; of goals onto objectives; and finally, a set of community objectives onto a set of items constituting a community work program. Expenditures of public revenues on each of the items of the work program may be considered as the decision variables ($x_1, x_2, \ldots, x_j, \ldots x_n$) of a mathematical programming formulation. For example, decision criterion j may relate to the "establishment of open space programs for metropolitan use"; $x_j$ would then represent the expenditure of public revenues in dollars on open space programs. A set of decision variables would be defined along with items of a work program in such a manner that every community objective would be represented by a work program item (or items) insuring the fulfillment of that objective.

## Conceptual Formulation of an Allocation Model

The preceding section defined decision variables. In considering a particular decision variable, $x_j$, it is possible to associate with that variable a "cost coefficient" indicative of the utility associated with the workprogram item represented by that decision variable.

It may be considered desirable to maximize the aggregate of the dollar expenditures multiplied by the utility value associated with each individual expenditure represented by the decision variables. The allocation of tax revenues must be performed within certain constraints. Such constraining relationships may be the availability of total money, the availability of other resources such as land, restrictions implied by time factors, desirable minimum or maximum levels of expenditure for various programs, or desirable interrelationships among the various work program items represented by the decision variables. Further, it would be logical to disallow any negative allocation of money.

## An Extremal Methods Approach

This section suggests several applications of standard mathematical programming techniques.

Linear Programming Formulation—The definition of decision variables was considered earlier. Consider a class of parameters ($u_j$) associated with the decision variables ($x_j$); the parameters represent the utility values associated with the various community work program items defined by the decision variables. That is,

$x_j$ = number of dollars allocated to community work program j; and
$u_j$ = utility associated with community work program j per dollar spent on community work program j.

An optimal allocation of available funds to the various work programs is represented by the following objective function:

$$\text{Max} \sum_{j=1}^{n} u_j x_j$$

where there are n possible work program items to which allocation may be made.

Constraints of the following form may be applicable:

$$x_1 + x_2 + \ldots + x_j + \ldots + x_n \leq b_1$$

where $b_1$ represents maximum available funds;

$$x_k \geq b_2$$

where $b_2$ may represent an absolute minimum expenditure such as required for education, police protection, or fire protection.

Due to constraints placed by time requirements associated with various projects, maxima may exist such as

$$a_{ij}\ x_j \leq b_1$$

In general, the problem may lend itself to formulation as the general linear programming problem stated as the maximization of a linear objective function subject to appropriate linear equality or unequality constraints. One constraint is that all allocations are non-negative.

Research in progress at Purdue University considers an optimal allocation of land uses. The formulation proposed could incorporate the concept of using criteria weights (utility values) as cost coefficients in the formulation of the objective function of a mathematical programming problem.

Parametric Programming Analysis—An interesting examination of the linear programming model by standard methods of parametric programming appears to be feasible. Changes in the cost coefficients or the utility values, as in this particular application, may be investigated, and the sensitivity of an optimal solution to changes in these criterion weights or utility values may be examined. Further, it may be possible by means of parametric programming analysis to determine the solution with a relaxation of the total money constraint or changes in other parametric values. With slight changes in certain "given" values, a much more desirable solution may be obtained.

Nonlinear Formulation of the Problem—An interesting concept of marginal utility is that additional incremental amounts of a given item are not as valuable as previous increments of the same size. For example, the third or fourth serving of a dessert would not be valued as highly as the first. Bernouilli and others have postulated that the utility function is not linear and may be described by an exponential or quadratic relationship. The methods of nonlinear programming may be applied in the situation of optimal allocation of community resources. The quadratic formulation proposed by Wolfe (5) or the more general convex formulation (10) may be applicable.

Dynamic or Integer Programming Approach—The powerful tool of dynamic programming has been successfully applied in problems where the decision variable is a 0-1 variable, i.e., in a situation where either an allocation is made or it is not made. Integer solutions may be indicated because of the practical situation where it would not be feasible to build a fractional or non-integer portion of a new school.

## Plan Evaluation

Many sophisticated techniques developed in the area of economic analyses of plans, particularly transportation plans, must be incorporated in an objective manner in the evaluation process. Much of the work in benefit cost analysis may be applied. Ultimately, an effective means of developing yardsticks to measure compatibility of plans with community values must be researched.

Plan evaluation must be concerned with the manner in which a plan is consistent with community values at a lower level of synthesis than the level of objectives studied here. That is, objectives are often too general and the resulting evaluation may be purely subjective. For use in evaluation of plans of traffic improvement at a more detailed level of analysis, the pertinent objective statements would be further subdivided to establish more meaningful criteria. This may be accomplished within the framework of the procedures presented here.

## SUMMARY AND CONCLUSIONS

This paper has presented an approach to the development of a decision model for evaluating alternative transportation system design concepts in the context of a comprehensive hierarchy of community goals and objectives. Various interesting approaches to plan evaluation were discussed as well as several proposals for utilizing potentially powerful normative procedures in system design. Extensive discussion of problems associated with community decision structure, formulation and weighting of goals and objectives, and the statistical analysis of weighting or scaling procedures is beyond the scope of this paper; however, a summary of findings in the areas mentioned is presented. The structuring of several decision models for the evaluation of alternative plans or alternative system design concepts with respect to a weighted hierarchy of community decision criteria is presented. Several immediate applications appear to be feasible and these applications are enumerated. A number of possible extensions of this research are identified. It is concluded that:

1. A decision model for use in systems evaluation may be simply structured to relate utility values associated with each element in a comprehensive statement of community decision criteria with the evaluation of effectiveness of given system alternatives with respect to these criteria. Simple extensions of such a model may provide for the stratification, by socioeconomic categories or other desirable categories, of the group of persons determining the utility values associated with the community decision criteria, or, for the stratification of professional planners, the group determining the plan effectiveness values.
2. In addition to their usefulness in plan evaluation as proposed in this research, weighted community decision criteria or quantified expressions of community values could be useful in system design and capital programming.
3. The procedures structured herein may be useful in the evaluation of alternative land-use forms, detailed alternative land-use plans, detailed transportation system plans, and alternative transportation corridors in addition to the application in evaluation of alternative system design concepts as presented here.
4. Although the community decision criteria considered herein were formulated for general overall community development, 80 percent of these criteria were judged to have a meaningful relationship to a specific problem of transportation system development.
5. The application of the plan evaluation model resulted in the selection of that system design concept based on some improvements of existing at-grade facilities with a balance of new freeway construction and rail mass transit. This plan possesses an aggregate plan utility 58 percent higher than that of the first design alternative (extensive improvement of existing at-grade facilities), and 15 percent higher than the freeway-oriented design concept.
6. Extensions of this work are needed in the areas of capital allocation model formulation and the associated definition of decision variables for such a model, and the development of effective yardsticks for determining plan effectiveness based on a weighted hierarchy of community decision criteria.

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# *Appendix A*

## STATEMENTS OF COMMUNITY GOALS AND OBJECTIVES

[General community goals (numerals) are subdivided into specific objective statements]

1. Public Safety Program Development
   (a) Insure safe public facilities.
   (b) Provide for adequate public safety regulations and their enforcement.
   (c) Provide for the removal of contaminants (solid, liquid, and gaseous).
2. Public Utility and Transportation Development
   (a) Minimize maintenance costs of public facilities.
   (b) Insure maximum effectiveness of public utilities, by design and locational considerations.
   (c) Develop a balanced, effective, and integrated transportation system which provides for the accessibility requirements of each land use.
3. Economic Development Programs
   (a) Develop public improvement programs within available financial resources.
   (b) Maintain highest equitable property values.
   (c) Insure effective utilization of mineral, vegetation, air, and water resources.
   (d) Establish a strong economic base through commerce that will bring money into the community.
   (e) Establish trade development that provides maximum convenience to consumers.
   (f) Insure the optimal utilization of all land.
   (g) Achieve increased disposable income for all people.
4. Cultural Development
   (a) Preserve historic sites and areas of natural beauty.
   (b) Promote adequate public libraries, museums, and cultural activities.
   (c) Protect meaningful local tradition and encourage civic pride.
5. Health Program Development
   Establish the mechanism for adequate preventive and remedial health programs and facilities.
6. Education Program Development
   Develop educational facilities and opportunities for citizens at every level.
7. Welfare Program Development
   (a) Eliminate injustice based on discrimination.
   (b) Develop needed public welfare programs.
   (c) Encourage development of religious opportunities.
   (d) Develop an aesthetically pleasing environment.
8. Recreation Program Development
   (a) Establish open-space programs.
   (b) Provide adequate recreational facilities utilizing parks, rivers, and lakes.
9. Political Framework
   (a) Improve the framework (channels, systematic use) for citizen participation in governmental functions.
   (b) Establish equitable taxation policies (bases, mixes, rates).
   (c) Achieve efficient governmental administration, representative of all citizens.
   (d) Develop adequate government staffs and personnel programs (high job standards, reasonable salary ranges, effective delegation of authority).
   (e) Establish sound governmental fiscal programs.
   (f) Develop an effective, long-range, metropolitan-wide planning process.
   (g) Establish effective control mechanisms.

10. Housing Development
    (a) Encourage rehabilitation and conservation neighborhood programs.
    (b) Provide adequate low-cost housing.
    (c) Develop neighborhood units.
    (d) Promote a wide variety of housing types as required within the community.

# *Appendix B*

## CRITERIA WEIGHTING TECHNIQUES

This Appendix presents a summary of techniques used in obtaining a weighted hierarchy of community goals and objectives. Fishburn (8, 9) lists and classifies 24 methods of estimating utility values. Recent research (7) has evaluated various methods of collecting the judgments of experts relative to the reliability and efficiency of these methods.

Ranking, rating and two variations of the method of successive comparisons are summarized here.

### Ranking Technique

Each member of the various judging panels was asked to place a raw rank by each criterion in the given lists of criteria. The most important criterion was assigned a raw rank of 1, the second most important, a raw rank of 2, etc. Criteria weights, or utility values, are developed as follows.

In general, there will be n criteria in a list of community goals or objectives. A converted rank of n-1 will be assigned to the criterion receiving a raw rank of 1, a converted rank of n-2 to the criterion receiving a raw rank of 2, . . . , and a converted rank of 0 to the criterion receiving a raw rank of n. The composite rank ($R_j$) for a given objective (j) will be determined by summing the converted ranks of all of the m judges; that is,

$$R_j = \sum_{i=1}^{m} R_{ij}, \; j = 1, 2, \ldots, n$$

In this expression,

$R_j$ = composite rank of criterion j,
$R_{ij}$ = converted rank of criterion j established by judge i,
n = number of criteria, and
m = number of decision-makers on the panel of judges.

The composite ranks thus determined are then normalized in the following manner:

$$u_j = \frac{R_j}{\sum_{j=1}^{n} R_j}, \; j = 1, 2, \ldots, n$$

where j = composite weight or utility value associated with community decision criterion j.

### Rating Technique

The rating scale technique is the most popular of all procedures used for collecting the judgments of individuals. The numerical type rating scale is used but descriptors are not associated with the integer points on the numerical scale. Appropriate descriptors that would not bias the judges could not be determined.

The lists of criteria to be weighted (i.e., the lists of community goals and objectives) are placed in a column adjacent to a scale marked in units continuously from ten to zero (top to bottom). A rating of zero indicates that there is no value associated with a given criterion and a rating of ten is the highest that may be assigned. Any value along the unbroken continuum may be assigned to any criterion. Even though an approximation will be made of non-integer ratings, the judge was permitted to associate with each criterion an integer or non-integer position on the rating scale. The rating assigned to criterion j by judge i is represented by $V_{ij}$. Utility values ($u_j$) or criteria weights for each criterion are determined in the following manner:

$$V_j = \sum_{i=1}^{m} V_{ij} \quad j = 1, 2, \ldots, n$$

$$u_j = \frac{V_j}{\sum_{j=1}^{n} V_j} \quad j = 1, 2, \ldots, n$$

Method of Successive Comparisons

The following procedures (SC-1) are based on the method of successive comparisons (3). The modification of the procedures is as follows.

Step 1 is carried out by placing the criteria in rank order by the utility value determined from the average results of the ranking and rating methods. Step 2 is completed by simply associating with each criterion that average value. The judges then were asked to check the rank order of the criteria as determined by consensus. If the judge agrees, the procedures move to Step 3. If he disagrees, he subjectively reassigns utility values.

Step 1. Rank the criteria according to preference:

$$G_1 \gtrsim G_2 \gtrsim G_3 \gtrsim \ldots \gtrsim G_{n-1} \gtrsim G_n$$

where $G_1 \succ G_n$.

Step 2. Tentatively assign the value $u_1' = 1.00$ to $G_1$. Then assign preliminary utility measurements $u_j'$ to the remaining criteria in such a manner that $u_j'$ seems to reflect the magnitude of preference for $G_j$.

Step 3. Compare $G_1$ vs $G_2 \wedge G_3 \wedge \ldots \wedge G_n$ or $G_1$ vs $\bigwedge_{j=2}^{n} G_j$

(a) If $G_1 \succ \bigwedge_{j=2}^{n} G_j$ then, if necessary, adjust $u_1'$ so that $u_1' > \sum_{j=2}^{n} u_j'$ and after making this adjustment go to step 4.

(b) If $G_1 \sim \bigwedge_{j=2}^{n} G_j$ then, if necessary, adjust $u_1'$ so that $u_1' = \sum_{j=2}^{n} u_j'$ and after making this adjustment go to step 4.

(c) If $G_1 \prec \bigwedge_{j=2}^{n} G_j$ then, if necessary, adjust $u_1'$ so that $u_1' < \sum_{j=2}^{n} u_j'$. Then repeat step 3 and compare $G_1$ vs $\bigwedge_{j=2}^{n-1} G_j$; that is, drop the criterion $G_n$. Continue dropping the least preferred criterion and comparing until situation 3(a) or 3(b) is encountered. This process must terminate since $G_1 \succsim G_2$ from step 1.

Step 4. Drop $G_1$ from consideration and repeat the entire procedure (steps 1 to 3) for $G_2$. Continue with $G_3$ and so on until the comparison of $G_{n-2}$ vs $G_{n-1} \wedge G_n$ is completed. Care should be taken to insure retention of the invariance in $u_1'$, $u_2'$, etc. That is, in adjusting values such as $u_2'$ the relationship $u_2' > u_1'$ must not be accepted in violation of step 1.

Step 5. The values of $u_j'$ obtained in steps 1 through 4 must now be normalized as follows:

$$u_j = \frac{u_j'}{\sum_{j=1}^{n} u_j'}$$

It is to be noted that the numerical values for $u_j$ are relative, hence the deletion or addition of a criterion $G_k$, where $u_k \neq 0$, would affect the values calculated.

Successive Comparisons Method: An Alternative Approach

An alternative procedure is proposed by Churchman and Ackoff (3) when a large number of criteria (7 or more) are to be considered. This alternative procedure may be useful in the specific application of weighting planning criteria. Churchman and Ackoff suggest the following alternative procedures:

Step 1. Rank the entire set of decision criteria on the basis of the average weights obtained by the ranking and rating techniques.

Step 2. Select the highest ranked criterion from the entire set. Let $G_s$ represent this standard criterion. By random assignment, subdivide the criteria that remain into approximately equal-sized groups of no more than 5 criteria per group. Each criterion, other than the standard $G_s$, should be included in one and only one group.

Step 3. Insert $G_s$ into each group and assign a criteria weight of 1.00 to $G_s$ (i.e., $u_s' = 1.00$).

Step 4. With modifications made above, follow the procedure of steps 1 through 4 of the preceding section to obtain unstandardized criteria weights (utility values) for the objectives in each of the groups formed in step 3 above. (Note: in adjusting the $u_j'$ values, do not change the value of $u_s'$.)

Step 5. Compare the ranking obtained for all criteria with the ranking of step 1. If the rank orders differ, reconsider the ranking and, if necessary, repeat step 4 of this alternative procedure.

Step 6. When consistent results are obtained, normalize the criteria weights by dividing the value assigned to each criterion by the sum of the values assigned to all criteria. That is,

$$u_j = \frac{u_j'}{\sum_{j=1}^{n} u_j} \quad j = 1, 2, \ldots, n$$

# Appendix C

| Criteria (See Appendix A for objective statements) | Weighting Techniques | | | | Average Values | | Range | |
|---|---|---|---|---|---|---|---|---|
| | Ranking | | Rating | | | | | |
| | $u_j$ | Rank Order | $u_j$ | Rank Order | $u_j$ | Rank Order | $u_j$ | Rank Order |
| 1a | 0.0142 | 26 | 0.0270 | 15 | 0.0206 | 17 | 0.0128 | 11 |
| 1b | 0.0505 | 6 | 0.0326 | 11 | 0.0415 | 6 | 0.0179 | 5 |
| 1c | 0.0648 | 3 | 0.0335 | 7 | 0.0496 | 5 | 0.0313 | 4 |
| 2a | 0.0000 | 35 | 0.0280 | 14 | 0.0140 | 31 | 0.0280 | 21 |
| 2b | 0.0611 | 4 | 0.0393 | 4 | 0.0502 | 4 | 0.0218 | 0 |
| 2c | 0.0611 | 5 | 0.0449 | 3 | 0.0530 | 3 | 0.0162 | 2 |
| 3a | 0.0217 | 16 | 0.0192 | 20 | 0.0204 | 19 | 0.0025 | 4 |
| 3b | 0.0031 | 34 | 0.0144 | 31 | 0.0087 | 35 | 0.0113 | 3 |
| 3c | 0.0311 | 9 | 0.0168 | 24 | 0.0239 | 12 | 0.0143 | 15 |
| 3d | 0.0248 | 12 | 0.0192 | 21 | 0.0220 | 16 | 0.0056 | 9 |
| 3e | 0.0155 | 21 | 0.0156 | 26 | 0.0155 | 26 | 0.0001 | 5 |
| 3f | 0.0279 | 10 | 0.0180 | 23 | 0.0229 | 14 | 0.0099 | 13 |
| 3g | 0.0279 | 11 | 0.0168 | 25 | 0.0223 | 15 | 0.0111 | 14 |
| 4a | 0.0089 | 31 | 0.0295 | 12 | 0.0192 | 21 | 0.0206 | 19 |
| 4b | 0.0248 | 13 | 0.0348 | 5 | 0.0298 | 9 | 0.0100 | 8 |
| 4c | 0.0069 | 32 | 0.0250 | 16 | 0.0159 | 25 | 0.0181 | 16 |
| 5 | 0.0925 | 2 | 0.1050 | 2 | 0.0587 | 2 | 0.0125 | 0 |
| 6 | 0.1555 | 1 | 0.1272 | 1 | 0.1413 | 1 | 0.0283 | 0 |
| 7a | 0.0173 | 20 | 0.0223 | 17 | 0.0198 | 20 | 0.0050 | 3 |
| 7b | 0.0124 | 27 | 0.0186 | 22 | 0.0155 | 27 | 0.0062 | 5 |
| 7c | 0.0035 | 33 | 0.0141 | 32 | 0.0088 | 34 | 0.0106 | 1 |
| 7d | 0.0111 | 29 | 0.0193 | 18 | 0.0152 | 28 | 0.0082 | 11 |
| 8a | 0.0148 | 24 | 0.0340 | 6 | 0.0244 | 10 | 0.0192 | 18 |
| 8b | 0.0148 | 25 | 0.0327 | 10 | 0.0237 | 13 | 0.0179 | 15 |
| 9a | 0.0206 | 17 | 0.0116 | 35 | 0.0161 | 24 | 0.0090 | 18 |
| 9b | 0.0149 | 22 | 0.0145 | 28 | 0.0147 | 29 | 0.0004 | 6 |
| 9c | 0.0218 | 14 | 0.0145 | 29 | 0.0181 | 22 | 0.0073 | 15 |
| 9d | 0.0103 | 30 | 0.0135 | 33 | 0.0119 | 32 | 0.0032 | 3 |
| 9e | 0.0149 | 23 | 0.0145 | 30 | 0.0147 | 30 | 0.0004 | 7 |
| 9f | 0.0206 | 18 | 0.0154 | 27 | 0.0180 | 23 | 0.0052 | 9 |
| 9g | 0.0114 | 28 | 0.0125 | 34 | 0.0119 | 33 | 0.0011 | 6 |
| 10a | 0.0321 | 8 | 0.0330 | 8 | 0.0325 | 8 | 0.0009 | 0 |
| 10b | 0.0195 | 19 | 0.0285 | 13 | 0.0240 | 11 | 0.0090 | 6 |
| 10c | 0.0218 | 15 | 0.0193 | 19 | 0.0205 | 18 | 0.0025 | 4 |
| 10d | 0.0413 | 7 | 0.0330 | 9 | 0.0371 | 7 | 0.0083 | 2 |

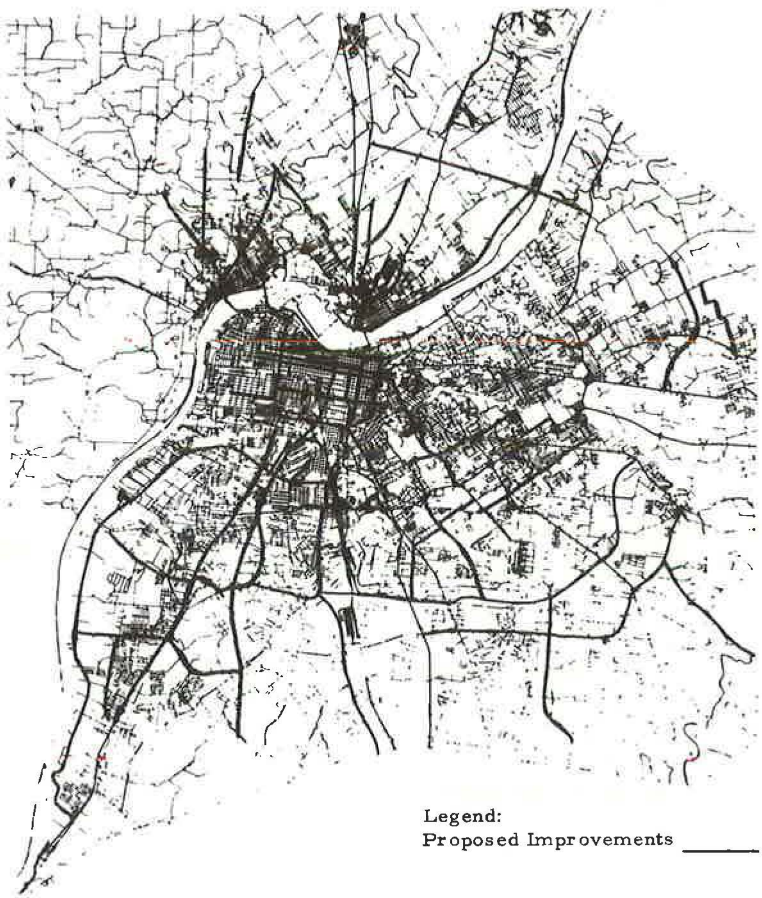
# Appendix D

| No. | Criterion (Objective) Statement | Effectiveness Value | | |
|---|---|---|---|---|
| | | Plan 1 | Plan 2 | Plan 3 |
| 1a | Insure safe public facilities. | 0.24 | 0.56 | 0.82 |
| 1b | Provide for adequate public safety regulations and their enforcement. | 0.32 | 0.76 | 0.64 |
| 1c | Provide for the removal of contaminants (solid, liquid, and gaseous). | 0.30 | 0.44 | 0.62 |
| 2a | Minimize maintenance costs of public facilities. | 0.44 | 0.60 | 0.62 |
| 2b | Insure maximum effectiveness of public utilities, by design and locational considerations. | 0.66 | 0.70 | 0.62 |
| 2c | Develop a balanced, effective, and integrated transportation system which provides for the accessibility requirements of each land use. | 0.40 | 0.62 | 0.84 |

| | | | | |
|---|---|---|---|---|
| 3a | Develop public improvement programs within available financial resources. | 0.72 | 0.74 | 0.54 |
| 3b | Maintain highest equitable property values. | 0.58 | 0.60 | 0.78 |
| 3c | Insure effective utilization of mineral, vegetation, air, and water resources. | — | — | — |
| 3d | Establish a strong economic base through commerce that will bring money into the community. | 0.44 | 0.76 | 0.94 |
| 3e | Establish trade development that provides maximum convenience to consumers. | 0.62 | 0.70 | 0.72 |
| 3f | Insure the optimal utilization of all land. | 0.62 | 0.68 | 0.76 |
| 3g | Achieve increased disposable income for all people. | 0.45 | 0.80 | 0.95 |
| 4a | Preserve historic sites and areas of natural beauty. | 0.52 | 0.60 | 0.72 |
| 4b | Promote adequate public libraries, museums, and cultural activities. | 0.66 | 0.66 | 0.70 |
| 4c | Protect meaningful local tradition and encourage civic pride. | 0.55 | 0.70 | 0.85 |
| 5 | Establish the mechanism for adequate preventive and remedial health programs and facilities. | — | — | — |
| 6 | Develop educational facilities and opportunities for citizens at every level. | 0.30 | 0.70 | 1.00 |
| 7a | Eliminate injustice based on discrimination. | 0.67 | 0.53 | 0.43 |
| 7b | Develop needed public welfare programs. | — | — | — |
| 7c | Encourage development of religious opportunities. | 0.30 | 0.70 | 1.00 |
| 7d | Develop an aesthetically pleasing environment. | 0.45 | 0.52 | 0.68 |
| 8a | Establish open-space programs. | 0.45 | 0.65 | 0.75 |
| 8b | Provide adequate recreational facilities utilizing parks, rivers, and lakes. | 0.70 | 0.66 | 0.54 |
| 9a | Improve the framework (channels, systematic use) for citizen participation in governmental functions. | — | — | — |
| 9b | Establish equitable taxation policies (bases, mixes, rates). | 0.68 | 0.62 | 0.32 |
| 9c | Achieve efficient governmental administration, representative of all citizens. | — | — | — |
| 9d | Develop adequate government staffs and personnel programs (high job standards, reasonable salary ranges, effective delegation of authority). | — | — | — |
| 9e | Establish sound governmental fiscal programs. | 0.67 | 0.67 | 0.40 |
| 9f | Develop an effective, long-range, metropolitan-wide planning process. | 0.60 | 0.68 | 0.72 |
| 9g | Establish effective control mechanisms. | — | — | — |
| 10a | Encourage rehabilitation and conservation neighborhood programs. | 0.70 | 0.62 | 0.58 |
| 10b | Provide adequate low-cost housing. | 0.40 | 0.53 | 0.80 |
| 10c | Develop neighborhood units. | 0.64 | 0.58 | 0.54 |
| 10d | Promote a wide variety of housing types as required within the community. | 0.42 | 0.62 | 0.82 |

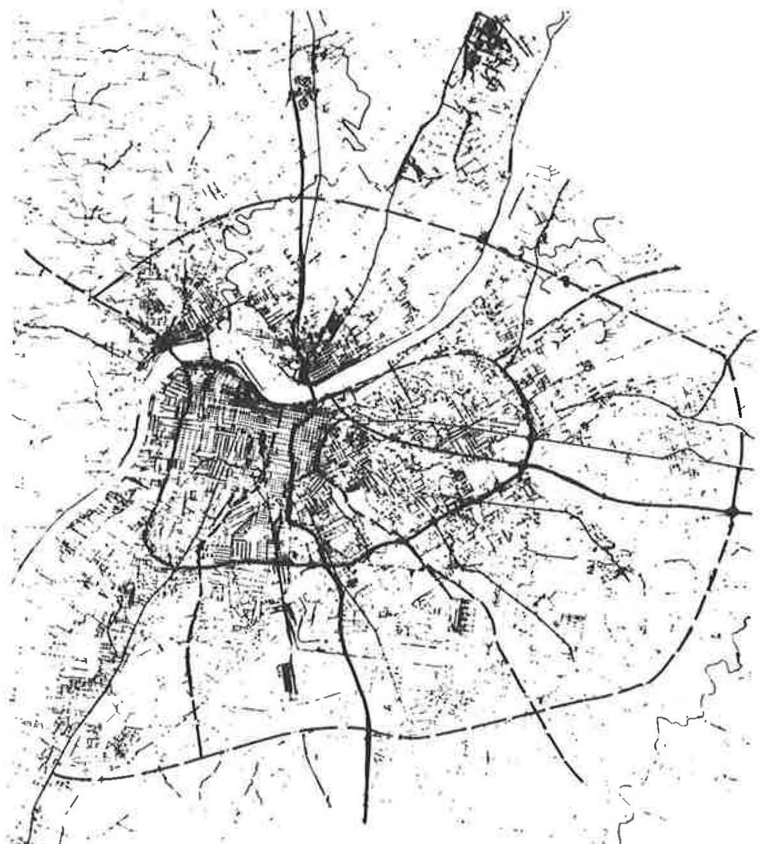
# *Appendix E*

ALTERNATIVE PLAN NUMBER 1: EXTENSIVE IMPROVEMENTS OF EXISTING ARTERIAL FACILITIES



# *Appendix F*

ALTERNATIVE PLAN NUMBER 2: MAJOR FREEWAY CONSTRUCTION, NO RAPID MASS TRANSIT



Legend:
Existing Freeways ___________

Proposed Freeways -----------

## *Appendix G*

ALTERNATIVE PLAN NUMBER 3: MAJOR FREEWAY CONSTRUCTION
WITH RAPID MASS TRANSIT