NEED FOR EXPLICIT TRANSPORTATION PLANNING PROCEDURES

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This paper develops the thesis that the major investment in formal methods in transportation planning studies has been in the field of analysis. This analysis covers three broad areas: data collection, statistical analysis, and model construction. The relation among these areas of investigation and theories of behavior and transportation systems performance are explored briefly. These questions are then enlarged to indicate the relation between the transportation system and the social and economic system (spatially distributed) that the transportation system serves, influences, and is influenced by. A transition to the second part of the paper deals with the optimizing nature of planning in general, as suggested by cost-benefit analysis and various decision procedures for the allocation of public resources. The mathematical program as a paradigm of the planning process is also briefly explored, and those elements that are to be discarded in the subsequent discussion are summarized briefly. The second part develops the contention that most actual transportation planning, as distinct from analysis, is conducted on an intuitive basis and according to professional practices that may or may not be well suited to the problem. A tentative sketch of the elements of these traditional methods as related to mathematical programming concepts is then developed. Several typical transportation planning problems are discussed. Finally, the utility and the nature of heuristic methods for finding optimal solutions to these and similar problems are sketched, and suggestions are made as to probable fruitful means of developing better planning systems.

•TRANSPORTATION planning is an activity that has long-term results. The facilities that are put in place now will still be operational to a large extent in the year 2020. In fact, a review of the history of many metropolitan areas shows that trails laid out by Indians and early settlers are still main channels of communication and transportation. Only in recent years, with major investments in the Interstate System, have some of these long-standing patterns been destroyed or modified, and it seems likely that new patterns established by new modes of transportation will have the same permanent effects as the early establishment of primitive trails.

One of the principal reasons for the persistence of channels of movement is what might be called the intensification effect of the interaction between land use and transportation. Principal transportation routes attract activities, and the growth of activities requires the improvement and expansion of transportation routes or the provision of supplemental and parallel facilities. This positive feedback guarantees the persistence of some patterns of activity and provides a major problem in planning.

Despite the long-term nature of transportation planning in principle, some recent developments have cast doubt on the utility of transportation planning as it has been practiced in recent years. These doubts arise from a number of sources: citizen opposition to the environmental impacts of the automobile, local resistance to the disruption caused by new facility construction, and growing uncertainty as to the technical future of power production, propulsion systems, and transportation technology in general. These three factors and some others suggest caution in the development of long-term plans. On the other hand, such long-term planning cannot be abandoned because of the anticipated size and durability of investments and because future provisions for transportation, except by air or tunnel, require the establishment and preservation of long and continuous corridors.

Federal and state governments and transportation planners have implicitly realized that these considerations are not to be taken lightly. Twenty percent of the U. S. gross national product is devoted to transportation. It has been fashionable to attempt to build a Machiavellian theory of transportation difficulties based on the magnitude of the supplier interests—the oil companies, motor companies, highway construction lobbies, and state highway officials. Although these vested interests do exist and undoubtedly contribute to the institutional inflexibilities with which transportation planning has to deal, there is another side to the problem. The fact that so much is spent on transportation directly implies that transportation plays a very important and positive role in the organization of our economy and our private lives. Such powerful economic forces, viewed from the consumer side, cannot be manipulated in either the short or the long run without serious large-scale investments in the planning and operation of a variety of facilities. It is also obvious that a very substantial intellectual and organizational apparatus has been developed for dealing with these problems of planning and providing facilities.

There are several major shortcomings of the planning process. The relative effort invested in detailed planning and engineering design of facilities as compared with the overall design of systems is disproportionately large. The emphasis in analysis and planning has been too responsive to the popularity of the automobile and has not until recently given adequate attention to other modes of transportation. There is an institutional anti-urban or at least pro-rural bias in the United States that has influenced the provision of transportation facilities. In transportation planning for urban areas, inadequate means have been developed for joint planning of transportation and nontransportation facilities, and the impact of transportation on land use has not been adequately accounted for.

I have taken the position for some time that the transportation planning process as currently conducted is up to a point a phenomenally successful and well-conceived enterprise. Let me define some of the best elements of this conception before defining some of the points where a shift of emphasis is needed to ensure adequate further progress. In this discussion, I shall focus principally on metropolitan-area transportation planning.

The origin-destination (O-D) survey and the approach to transportation analysis that arises out of it are remarkable examples of a type of behavioral social study. The uniqueness of such studies is especially remarkable because their principal development came from engineering.

The use and manipulation of the masses of data produced by O-D surveys and other parts of major transportation studies required the development of substantial competence in data management and manipulation. These competencies expanded into the field of computer utilization, from which has come computerized data manipulation and computerized models.

The models of transportation behavior that are a well-standardized part of most metropolitan transportation studies are to a large extent more complex than a great many models of related types that have been devised or suggested by economists and sociologists. I maintain that these models are essentially behavioral and that they are frequently superior to the substitutes proposed by critics. I am not aware of any other field in which such massive detailed projections can be made by reasonable and systematic means. In spite of this overall endorsement of the general package of transportation demand projection, I still have many reservations. One such reservation is that the models appear to be lacking in generality. If this were not so, a single model package could be applied without new surveys to almost any metropolitan area in the country. This lack of generality is of utmost importance in considering long-term projections making use of new transportation technologies and new land-use arrangements; if a predictive procedure cannot be generalized in 1970, it is very difficult to see how it can be applied to 2000 or 2020.

The evolution of transportation demand modeling has followed a familiar inductive paradigm. In the earlier stages of O-D surveys (and continuing to some extent to the present) relations were established through simple statistical models (for example, the classical gravity model). The computer has greatly expanded the capability of transportation studies to deal with large masses of data and substantially expanded numbers of variables in this most simple statistical framework. Such statistical analyses following on data collection constitute, of course, an important and possibly essential step in the development of a predictive capability. This step, however, is not complete without the use of models in a more sophisticated sense. This sophistication takes two distinct but related forms. The first of these is computer simulation of large systems. The prototypical example is Morton Schneider's original program for trip distribution and assignment. Typically, such a large system simulation makes very heavy use of computers and permits the manipulation of very large numbers of elements. I have purposely not tried to make a narrow definition of this system simulation concept because it exists independently of the content of problems in the mind of the model builder, although its specific form is in each case ultimately determined by the nature of the problem that is being solved. We now know that there are perhaps three major formal questions influencing the structure of these models, each of which must be answered in a larger context. These questions are whether a dynamic model is needed, what types and levels of aggregation are to be permitted, and what importance is to be given to stochastic events.

The second aspect of modeling has to do with content. A typical example in this area might be a generalized model of modal choice. This example illustrates the fact that, after 30 years of experience with transportation modeling, 15 of them quite intensive, there are many aspects of behavior in transportation demand that are still inadequately understood by transportation planners. The example also shows that there is a tendency for basic research in the transportation field to be driven from the level of aggregated and descriptive models to the level of individual and household behavior. Finally, these models will in all probability turn out to be not generally susceptible to the naive statistical methods that were in vogue 15 years ago; they will probably require concepts and methods having to do with nonlinearities, discontinuities, and other troublesome aspects of realistic models of individual behavior.

The partial solution of all of these problems in the prediction of transportation demand (and the difficulties that arise in trying to extend these successes) gives impetus to the development of new models in the field of urban land use, the delivery of urban services, and some aspects of urban social interaction. This field is deeply indebted to transportation planning for data, statistical methods, computer systems, and the initial steps in understanding spatial processes. The need for solving some of these problems has risen in transportation planning from at least two sides. First, it is now quite clear that transportation is an intermediate service that meets defined social and economic needs and, as such, cannot be considered in isolation from these needs. The original transportation study land-use projections recognize this interaction in an elementary way, but the need for detailed knowledge of the functioning of the system has increased as problems of equity have come to the fore. On the other hand, the development of land uses in response to the provision of transportation had unanticipated consequences on the performance of transportation plans. Plainly, it is beginning to be recognized that the general purpose of planning is to improve jointly the system of transportation services and land uses and that each may be used as an instrument to influence the behavior of the other. All of these considerations have led to the development of locational models that are partly related to and partly independent of transportation planning and transportation analysis.

If we take a broad view of all of this work, we can be reasonably well satisfied with the extent to which such planning is widely understood and widely disseminated through the highway engineering and highway planning profession, partly through the efforts of the Highway Research Board. We must be disappointed that the land-use modeling effort has not received the same systematic development and dissemination. We must still be dissatisfied with the nature and limitations of some of the models currently in use, but most particularly we must define and acknowledge a specific limitation of this work with very far-reaching consequences. Almost without exception, data collection, analysis, and model building serve two important planning purposes that are necessary but not sufficient for a successful planning process. The first and perhaps minor purpose is to establish a baseline description of the status of the system and the metropolis at the beginning of the planning period. The second and dominating role of these models is to predict the performance of plans or proposals. Subject to the many qualifications mentioned previously, transportation demand models in particular can now project the response of the system to major changes in the system itself and in the environment. This is done at a scale and level of detail that is remarkable for social science modeling; however, the entire apparatus stops at the point of making predictions. The planned changes that are the object of policy-making are entirely outside the modeling system. It is now appropriate to turn to the source of plans and to discuss the process by which they could ideally be generated.

Two different major views of the objectives of transportation and land-use planning may be developed depending on personal predilections and roles within the planning process. A short-range view of the planning process emphasizes the main constraints that have been previously mentioned. In the light of these constraints, it is sometimes difficult to find a plan that can feasibly be applied with any hope of using available funds or meeting a subset of local needs or both. In a variety of ways, transportation planning viewed in this way is very constrained, and the problem to be solved is only that of finding a feasible solution.

The difficulty with this type of planning is that its continued exercise may lead the total system in undesired directions. I therefore lean to the second view, which maintains that, over the long run, major changes can be made in the total system. In effecting these changes, dealing properly with the constraints is an important activity. If necessary, redefining them or removing them can be accomplished. Viewed in its totality, long-term planning attempts to approach an optimal solution to the problems with which it is designed to deal—in this case, transportation and land use. Such an effort has to take into account resource and social constraints and the costs of actually searching for an optimal solution. There are many indications that the principal thrust of public policy is in the direction of optimality rather than feasibility. Stylized procedures such as benefit-cost analysis, cost effectiveness, and program evaluation are all designed to focus public action on the most effective use of resources. A similar result is also achieved through emphasis on "balanced programs," in which no more efficient allocation resources can be found by transferring expenditures from one item to another. In what follows, therefore, despite many important qualifications, I will treat the problem of planning as if it were a problem in optimization.

The principal paradigm for optimization (and a most useful one for discussing the structure of the planning process) is mathematical programming. At a later point, I shall suggest that planning as it is and should be practiced cannot conform with this paradigm, but, at this point in the discussion, it is necessary to develop and fix ideas with respect to the nature of optimization. Every mathematical program has a handful of principal features whose analogs are in most cases easily recognized in the planning process.

Each program has an objective function or measure of performance that must be maximized or minimized. In planning parlance, this represents a weighted set of goals or, in more sophisticated terms, some sort of social welfare function. There are many difficulties in composing such an objective function, and these are especially acute in a pluralistic society and in times of relatively intense social conflict.

Mathematical programs are subject to some set of constraints. These constraints may be social, political, economic, or natural. Very frequently the constraints represent social goals that are established outside of the program and for which, beyond certain levels, no trade-offs are permitted. In most cases, the imposition of constraints makes it easier to solve a mathematical programming problem, but, at the same time, these constraints foreclose choices that might be important in the planning process.

In addition to providing an objective function and constraints we must frequently structure the problem in some particular manner. These structures have two different roles. In the first instance, they may be purely definitional or mathematical and serve the purpose of framing the problem so that it is more easily solved. In the second place, they may involve some correspondence with the real world, for instance by expressing the hierarchical nature of a metropolitan governmental organization or of a highway system. Frequently, the natural structure provides a basis for solution simplifications, as when the hierarchical nature of a problem permits a technical decomposition into interacting subproblems.

Next, every mathematical program has a systematic procedure for searching the solution space, by which it is guaranteed that the optimum will be found. We define solution space as all possible combinations of decisions that do not violate the constraints. One of the principal objectives of mathematical programming is to specify a means by which this optimum may be found by eliminating many solutions on logical grounds rather than examining every individual one.

Finally, and most important for purposes of this discussion, every mathematical program has to include an evaluation process by which, as the successive solutions are examined, their value or performance is established and a basis is laid for searching for the next step in the improvement process. Ordinarily, in mathematical programming, calculation of this new objective function is very simple. In linear programming, for example, it arises automatically out of the selection of each successive improvement of the solution.

It is the nature of large combinatorial problems that the number of possible solutions is extensive and that considerable attention must be given to all of the foregoing aspects of the problem of finding an optimum solution. In transportation and land-use planning, the number of variables and interactions is very large, and even the simplest possible formalism—that of linear programming—can readily generate complex problems. If in addition we add other conditions that generally exist in these types of problems, the number of steps in a solution becomes still larger. These complications include nonlinear objective functions, nonlinear constraints, zero-one or integer values for the variables, and multiple local optima. It may be categorically asserted that, for the overwhelming bulk of these problems and even with the simplest possible calculation of the objective function, it is impossible to explore all local optima and to find the optimum optimorum.

There is, however, one main and related subsidiary point of overwhelming importance when we consider the relation of the foregoing paradigm to transportation planning. The principal point is that the evaluation of the worth of a transportation and land-use plan is a cumbersome and extended process. For even a simple number of evaluations using currently existing techniques, scores of thousands of dollars worth of computer time and scores of man-years of staff time are necessary to specify elaborate plans, predict and tabulate the results, and evaluate these predictions according to some standards of decision-making. The subsidiary aspect of this problem is that the current techniques for predicting impacts on transportation and land-use plans do not lend themselves well to generalizations and simplifications. Thus, if we ask what the relative impact of two different levels of capital budgeting for transit systems would be on the city of Philadelphia, we would probably receive an answer that this requires the complete evaluation of selected proposed plans embodying these levels of expenditure. Some procedures of plan-making urgently require the ability to make decisions at a high level of generality to eliminate or "bound out" certain lines of development. In the absence of generalized evaluation techniques, the entire planning process becomes even more difficult.

We may now express one of the most difficult aspects of the urban metropolitan planning process in terms of a rather straightforward contradiction. On the one hand, our present tools for the analysis of proposed plans are quite accurate, but they are elaborate and cumbersome. We have no easy way of analyzing the impacts of either small changes in plans or decisions at the most general level. The available resources therefore permit the exploration of only a very few well-developed cases. On the other hand, a complete optimizing process involves very extensive explorations of possible solutions. Even in those numerous and quite general cases in which a complete implicit exploration is impossible, ordinary prudence would dictate that we explore a substantial number of useful plans, including some rather "far-out" solutions, before developing a limited number of final schemes in detail. A failure to follow this procedure most probably results in overlooking important and innovative solutions to problems that might usefully receive more consideration.

In general, my conclusion is that there is an imbalance in effort between the improvement of plan evaluation methods (including the prediction of demand) and the improvement of planning methods themselves. I would not recommend any cutback in the first effort because the total resources devoted to these two developmental activities still fall far short of a desirable level. There is a great deal more room for improvement in the design of our systems than present analysis and design or planning techniques can achieve. My general suggestion therefore would be that what is needed is a moderate augmentation of research in prediction and plan evaluation and a considerable increase in the investigation of planning methods. In the remainder of the paper, I will discuss some of the more salient aspects of planning methodology and possible steps toward its improvement.

It is obvious that, when confronted with the paradox just discussed, the average transportation planning study has a number of systematic methods for reducing the contradiction to manageable proportions. One such method is to use simplified models of prediction and evaluation, but this option is not openly available although we will see that it appears to be implied by some other simplifications. Most of the reduction in effort in exploring a wide range of possible plans is done by paring down the choices that are believed to be useful. It is apparent, therefore, that transportation planners have a hidden agenda by which planning choices are narrowed down and a final limited number of sketch plans are arrived at. The principal difficulties with this hidden procedure are the following. First, because the plans are not publicly known, they cannot be criticized by those interested in the outcome of the transportation planning process. Second, because such plans are arrived at in private, it is impossible for interested members of the public to intervene at the early stages. Third, because the process is somewhat personal and individualistic, it cannot easily be replicated. Thus, different planners might achieve basically different results. Fourth, because the procedure is not explicit and well-defined, it cannot be validated or usefully employed by others to vary the starting assumptions and achieve differential results in a systematic way. Fifth, as in all of the preceding cases, it is difficult to systematically transmit knowledge about such hidden planning methods, and the instruction and training of good planners are extremely difficult. All of the foregoing argues for the idea that planning should be conducted by a process that is well-defined, publicly known, open to examination and intervention at various points, and reproducible and that has a clear separation between those parts that depend on individual judgment and those parts that may be considered automated or computerized.

There are two principal forces driving transportation planning in the direction of a more completely specified procedure along the foregoing lines. The first of these is the increasing public concern over the way in which transportation plans are developed and over their impacts on neighborhoods and on the environment, and the second is the increasing difficulty and complexity of transportation planning. Such difficulty and complexity arise out of the increased number of choices that can be made in an affluent society and out of the technological uncertainty regarding the future of transportation itself. In order to understand how such a policy might be more specifically articulated, we can compare some of the things that planners actually do with some of the processes that arise in the formulation of mathematical programming solutions to the problem of optimization.

The formulation of the objective function is equivalent to the definition of social goals and is receiving increasing attention in many aspects of governmental planning. The advance formulation of goals proceeding from the abstraction of general social welfare down to concrete operational policies is an exceedingly difficult process, precisely because it is approached in the abstract. Fortunately, planning is a cyclical process, and the actual procedure of articulating plans and submitting them to public discussion tends to clarify the nature of the goals held by the planners, decision-makers, and public at large. This particular aspect of feedback in the planning process deserves substantial strengthening in transportation planning. It is quite true that there is a large-scale public desire for improved highway transportation that has been recognized by transportation planners in the Federal Highway Administration. At the same time, however, the attention to public thinking in the content of transportation plans and concern with alternatives both within the automotive system and between the automotive and other systems have been totally inadequate. The formulation of goals and objective functions is not, however, the principal part of the process with which I am now concerned.

Planners customarily develop constraints that, in one or another sense, reduce the number of possible solutions to their problems and in all likelihood simplify the solution in other ways. In connection with transportation, these constraints may be budgetary, legal, customary, or physical. All of these constraints are subject to change in one way or another, and, if the costs of the changes could be specified, they could be removed from the constraint set and placed in the objective function. This would permit greater flexibility in planning so that a wider range of choice might become available. The formulation of constraints therefore represents an advance decision by the transportation planner that, outside of certain bounds, the costs or discontinuities of selected policies are excessively burdensome. For example, the idea of congestion pricing of highway facilities is ordinarily ruled out of plan formulation and testing because it is currently not legal in most aspects of federal highway construction. In addition, this legal provision is based on a long-standing customary tradition, and changing it might involve considerable political difficulties. Finally, the technical problems of charging and enforcing congestion pricing are considerable. In the short run, all of the reasons for maintaining a particular constraint on transportation planning are valid. Many constraints of this type also gradually arise as standards of engineering practice and are applied almost without thinking by transportation planners. In most cases, these professional standards are probably well justified, but in some they may have outlived their usefulness. A constant flexibility as to the possibility of changing standards and constraints should be a part of the transportation planner's operating rules, and every effort should be made to specify both implicit and explicit constraints so that the concerned public may understand the rationale behind some aspects of transportation planning.

The most troublesome part of transportation planning involves the development and testing of an adequate variety of alternatives. This difficulty may be said to arise at every level in the planning process, from the smallest elements of facility location to the largest aspects of total system design. To suggest that there are various levels in the process already anticipates the suggestion that it is probably possible, at least in certain respects, to break down the planning of the transportation system in a hierarchical fashion. It also appears likely that a hierarchical breakdown corresponds in its structure to certain large-scale engineering aspects of the problem. We may point out that this is not necessarily the case, although its logic is embedded in a great deal of transportation planning and analysis. The decomposition could be hierarchical by political jurisdiction or in some other fashion by type of movement such as people versus goods and trip purpose.

Decomposition principles for solving large mathematical problems are gradually becoming more important and can often be implicitly related to the practical decomposition of problems both in the real world and in the planning process. Three important features of this decomposition must be borne in mind. First, the system that is being decomposed should itself be adequate in size for dealing with the total problem, properly defined. Second, the decomposition should facilitate rather than confuse or complicate the solution of the problems. Third, there must be a reciprocal iterative relation among the different levels of the decomposition. The last provision means that we cannot plan lower level systems once and for all without referring back to the larger context in which they are embedded and evaluating the larger system. This evaluation may impose changes on our previous plans for the lower level systems. It seems probable that one source of public dissatisfaction with transportation planning has been inadequate attention to the interaction among subsystems. The decomposition occurs at a very high level in the federal government, and what might be called "recomposition" at the local level, where the systems interact, is very difficult. In addition, we should note that, because the federal government has very little responsibility for land-use planning, this aspect of the system is not automatically included in the total problem subject to decomposition.

A hierarchical approach to decision-making facilitates the process known in mathematical programming as "branch and bound," by means of which large classes of solutions are ruled out. If it can be readily shown that certain combinations of high-level decisions are impractical or have a very low benefit-cost ratio, all the subsequent decisions that might depend on these can be aborted. Thus, for instance, a large-area metropolitan transportation plan that calls for all transit or all automobile facilities could automatically be excluded. The difficulty with these large-scale exclusions is that they depend very substantially on planning intuition and not on a direct evaluation of their implications. We urgently need predictive methods that can evaluate a partial statement of a plan rather than a fully developed and articulated plan. Such evaluations ought to be scientifically based and open to public inspection. Obviously also, as with all other prediction methods to be discussed, speed is an essential element in guaranteeing the capability of exploring a large number of possibilities.

Some principal large-scale options in urban transportation planning are configurational in nature. A typical example of this general approach is the year 2000 exploration for the Washington area. In these explorations, the gross interaction between land use and transportation was made perfectly apparent and was to some extent systematically explored. We need, for each particular case of configurational planning of this type, a method for specifying different configurations in a meaningful way that facilitates systematic explorations. In giving a related illustration of the difficulties in this matter, Marvin Manheim offered a hierarchical approach to highway route location that started at the highest level with the assignment of broad bands of location for every exploration. The possible number of these bands is infinite in continuous space, and no systematic procedure was proposed for exploring them without either major duplication of effort or major omissions of likely potentialities. In general, these are the twin dangers of any ill-defined exploratory procedure.

Even better definition will not completely eliminate the possibility of missed combinations. At some level of decomposition of a general planning problem, a level of detail may be encountered where there is some hope of actual optimization. I specify that this is largely a hope because, in the overwhelming majority of practical cases, the hope cannot be fully realized. Nevertheless, subject to the conditions established by higher level planning assumptions, certain problems can be examined in some detail, and fairly firm plans can be developed. What is too often forgotten is that these detailed plans depend in very large measure on the assumptions of the decomposition. As the planning problem is reexplored with a different combination of high-level assumptions, the subsystem optimization should produce different results.

A simple illustration that provides very many interesting sidelights is the problem of route location that constantly arises in highway and transit planning and that has generated many of the most difficult current political problems in plan implementation. This problem was explored graphically by Alexander and Manheim in a manner somewhat different from the more systematic treatment by Manheim mentioned previously, but these graphic methods have been used in a number of other situations including some criticisms of route location decisions mounted by citizen groups. If the sole problem is to connect two separated points by a facility, the graphical methods involve using a set of overlays that show impediments to route location at various levels of intensity. These may be natural physical features, cost of land acquisition, environmental damage, destruction of historical monuments, concentrated political opposition, and so forth. These graphical representations can be overlaid and "eyeballed" to select what may be believed to be a superior or even optimal location. In this simple form, the problem is easily converted to a dynamic programming minimum-path problem that can be solved very rapidly with current computer techniques. It would be quite possible to vary the weighting of the different impediments to route location so as to express the different value systems of participants in disputes. These might then produce a variety of different route locations that could be examined and discussed much more intelligently than has frequently been the case.

It is very rare that a complete optimal solution of the type just described can be found and implemented. Even the simple route location problem rapidly becomes more complicated in a real-world situation. First, there are many hidden and complicated features that may be overlooked in generating data for a model of the type described. Second, there are impacts, such as community disruption, that we are not yet able adequately to measure and model. Third, the problem as defined neglects, for example, the important aspect of service to intermediate points. The real nature of the problem therefore rapidly escalates to one that must be solved by so-called heuristic methods. It is at this point that we need a more active effort to specify what can be done by computer and what involves human intervention. Also a more precise specification is necessary of what form the intervention will take.

A similar example is the problem of network optimization. Here again, there are no completely successful optimizing models. Branch and bound techniques have been found to be excessively time-consuming on all but the smallest problems. The very interesting optimal spacing suggestions of the Chicago area transportation study are not deterministic with regard to the actual location of network links. They provide a general concept of how a system may be brought to a balanced state where the benefit-cost ratios are uniform throughout the system. Here again, heuristic techniques are urgently needed.

Probably the most important single element of heuristic search is a means for improving given solutions systematically. In the more complicated route location problem, this might be a systematic means for making small displacements of different parts of the route that would cumulatively lead to a locally optimal solution. In the optimal network problem, such an improvement method would most likely be swapping, or the deletion and addition of links to the system, once again leading to a local optimum. The essential problem in each such case is to formulate the problem correctly: first so that a systematic improvement may actually be hoped for and second so that the computation of these improvements is extremely rapid. Exactly this form of systematic improvement is used, for example, in linear programming, but it is not heuristic because it is guaranteed to find an optimal solution.

This observation leads me once again to reemphasize the local nature of optima achieved by stepwise improvements of plans. As a simple example, if the route location problem is being solved by incremental adjustments and the route has been located on the wrong side of a mountain, it will probably never be moved to the right side. It is thus highly probable that, even for relatively low-level optimization problems, the difficulty of exploring distinctively different alternatives still exists and can be very troublesome.

It may also be well to reemphasize at this point the fact that the optima achieved in solving a lower level problem depend very much on the terms in which those problems are framed, that is, on higher level policy decisions that may be involved in a decomposition procedure. The optimal network problem obviously depends on land-use and locational decisions, overall level of spending, various constraints, and the way in which the objective function is formulated at the high level and disaggregated for application to the particular subproblem. Similar observations could be made about the route location problem. In the simple problem, the objective function is probably the principal determinant of route location. As the problem is made more complex, all of the other features that have been discussed may gradually enter into its solution.

If it were desired to optimize land uses and location with the transportation system fixed, similar decomposition problems arise. It seems likely, for example, that, except for social externalities or social preferences, residential location patterns by themselves could be optimized by a linear programming approach. On the other hand, the industrial assignment problem of locating interacting industries is a quadratic programming problem that becomes very difficult to solve for large numbers of locators. This quadratic programming problem could be extended jointly to include the location of residences and workplaces, once again given a fixed transportation system. These problems are in their own way every bit as intractable and difficult for land-use planners as the problems that I have discussed previously are for transportation planners.

I mention these land-use optimization problems because, for large urban metropolitan areas, it seems likely that the real planning problem is not to optimize either transportation or land use but to optimize them jointly. Curiously enough, this idea was proposed in a more limited context in a memorandum from Robert Murray Haig to the New York Regional Plan Association almost 50 years ago. He suggested that the best urban plan would be the one that minimized the total of transportation costs and land rents. This simple concept was proposed as a subject of study for the Association, but was not what Haig himself was able to carry out. The roughly described solution method corresponds in a general way with linear programming, which was not developed until 20 years later. Haig was principally concerned with land use and did in fact assume that the transportation system was fixed. This, however, is by no means a necessary assumption, and, for sufficiently drastic changes in land uses, it is obviously untenable. I am not aware that anyone has proposed a practical means for systematically tackling this combined problem, let alone a rigorous one that would produce truly optimal results.

I hardly need emphasize further the fact that the size and complexity of metropolitan planning problems, together with their nonlinearities and discontinuities, make mathematical programming solutions of the global problems largely infeasible. This unfortunate fact greatly magnifies the importance of heuristic methods. In the context of this discussion, these heuristic methods introduce two more or less distinct acts of an artistic or creative nature into the planning process. Neither of these creative activities can be made into an explicit and reproducible planning process. The best that can be done is that they may be justified after they have been completed on the basis of general acceptance.

The first of these acts is the design of the heuristics themselves. They can be rationalized or sketched out in the terms that I have used in the introductory portions of this paper, and their justification may be more firmly established. Heuristic methods will ordinarily contain in the second place steps of human or planning intervention where the inputs are also creative and where the final justification can only be on the basis of results. Here, however, there is a subsidiary point of very great magnitude. Not only are some suggestions bad, but a preoccupation with mediocre suggestions may prevent finding a really first-rate solution. For this reason, the importance of brainstorming and counterplanning should probably be enhanced so that alternatives may be generated outside of the planning process itself. A greater openness on the part of transportation planners to this kind of intellectual and popular input should be a final and most important ingredient in a new style of transportation planning.