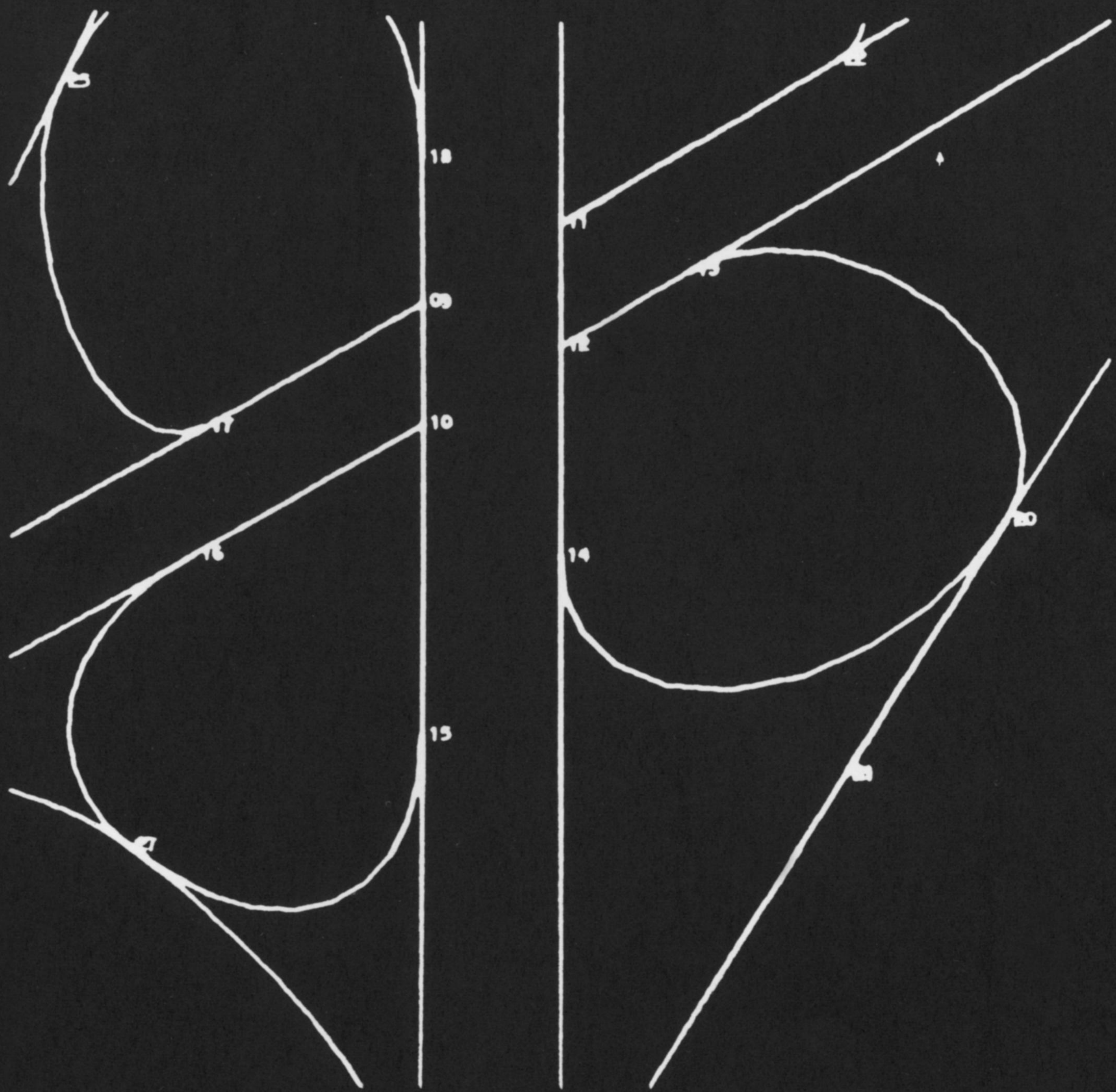
Problem-Solving Processes in Planning and Design
Author(s): Marvin L. Manheim
Source: *Design Quarterly*, No. 66/67, Design and the Computer (1966), pp. 30-39
Published by: Walker Art Center
Stable URL: https://www.jstor.org/stable/4047330
Accessed: 08-08-2024 18:36 UTC

Highway interchange photographed on the screen of a cathode ray tube. The designer can modify the design and recall an enlargement to examine or work on a detail.



PROBLEM-SOLVING PROCESSES IN PLANNING AND DESIGN

by Marvin L. Manheim

Dr. Marvin L. Manheim is assistant professor in the department of Civil Engineering at the Massachusetts Institute of Technology, Cambridge, Mass. He is particularly interested in the role of the computer in design and has published papers and reports concerning this subject. Together with Dr. Christopher Alexander, Prof. Manheim worked on research projects in the area of highway route location and the design of highway interchanges.

The Problem-Solving Process as presented here should be understood as a system for solving complex design problems with the use of computers. Projects like the route location of a new highway and problems in architecture or city planning are of such complexity that the computer should be employed as a tool for analysis and prediction. The Problem-Solving Process is a sequence of procedures with emphasis on Search and Selection. To achieve the most correct action or plan within a complex situation, different methods are used to produce alternatives and then a preference ordering of these actions is established. The most desirable plan is selected and implemented. The designer decides what parts of the procedures the computer should be used for and retains the prerogative to find alternative solutions with his own creative talent.

Properly designed highways, hospitals, bridges, etc. are urgently needed. Therefore, the most efficient means should be used to find solutions within the given restraints of time, costs and manpower. The trial and error possibilities inherent in this Problem-Solving Process are most valuable since they make it possible to test, re-evaluate and revise any design situation. This is extremely important if we realize that a highway, building or bridge once designed and built cannot be removed as one would withdraw a badly designed product from the market.

In design and planning, problems of increasing complexity have to be solved today. Computers and elaborate programming techniques can now assist the designer in finding solutions to highly complex problems. To utilize these technologies effectively, it is necessary to better understand how man and machine can work together successfully in attacking complex problems. A general theory of Problem-Solving Processes, particularly applicable to planning and design, is needed.

The necessity for such a theory is emphasized by some very exciting work being done in computer graphics — the various ways in which information and images generated by the computers can be displayed and operated upon. But the availability of such techniques alone will not enable the designer to utilize these accomplishments in the planning and design process. He must be able to answer such fundamental questions as what information should be displayed, when, how, and at what points in the process.

The objective then is to formulate a theory which can be implemented and useful. The Department of Civil Engineering at the Massachusetts Institute of Technology is developing an interrelated system of computer programs for addressing a broad spectrum of design and planning problems in civil engineering, soils, structures, water resources, transportation and other areas. This system is called ICES (Integrated Civil Engineering System). Hopefully, many of the following ideas will be implemented in this system and subsequently tried out in applications to transportation and other engineering, planning and design problems.

Apart from this pragmatic objective, the ideas presented here are still exploratory and tentative. They are biased toward transportation planning, city planning and economic planning; but it is hoped that they will also apply to design, especially architecture, and the general problems of socio-political planning.

A "Problem-Solving Process" is defined as any man-machine system interacting with a problem in order to develop, select, implement, monitor and revise actions in the real world. The characteristics of this Problem-Solving Process should be identified so completely that the model is applicable to problems in architecture, design, transportation, urban and economic planning.

The Problem-Solving Process is visualized as containing a variety of procedures to be used in the Problem-Solving Process when and as appropriate. The emphasis is on the concept of a "process": a sequence of many different kinds of activities.

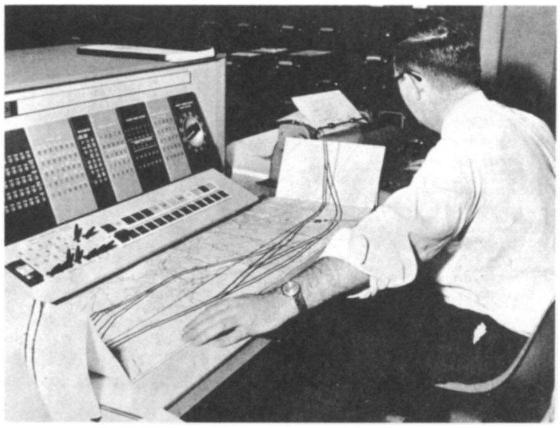
The basic frame of reference is the new computer hardware and software which can provide, by use of the "time-sharing" systems,[1] a flexible, highly-interactive service to many designers through remote-access consoles.

An example from the area of transportation planning should demonstrate the need for thinking in terms of a total Problem-Solving Process and show just how complex real problems can be.

The basic characteristics of a transportation planning problem are reflected in:

a) The variety of options open: In transportation planning the alternative options (facilities, vehicle modes, operating policies, etc.) are not well defined, and cannot be easily generated or enumerated. They are too complex to describe and very difficult to manipulate.[2]

b) The variety of impacts which must be considered: The impacts of transportation planning such as construction and maintenance costs, tax revenues, population displacement and changes in social structure are also numerous and not well defined. Evaluating the full set of impacts for each alternative plan is diffi-



Computer-oriented systems are being adapted to the language of the highway engineer to evaluate highway location and design decisions.

Plotter attached to an IBM data processing system automatically plotting highway location designs.

cult as many desirable and undesirable effects must be balanced, and no single "quantitative measure of effectiveness" is available to summarize the issues.

c) The number and complexity of interactions of the different transportation models required to predict the impacts of a specific plan: Predicting such impacts is computationally very difficult, relatively expensive and, in the end result, still uncertain.

Because of the *variety and complexity of the options,* the space of alternative plans is not well structured, which makes the production of desirable alternatives very difficult. Because of the *variety of impacts,* no *single* criterion function can be optimized. Because of the number and complexity of the transportation models which are available to the designer, determining the desirability of a new alternative is also difficult. For these reasons, a single optimizing model or plan can never fully solve such a transportation problem.

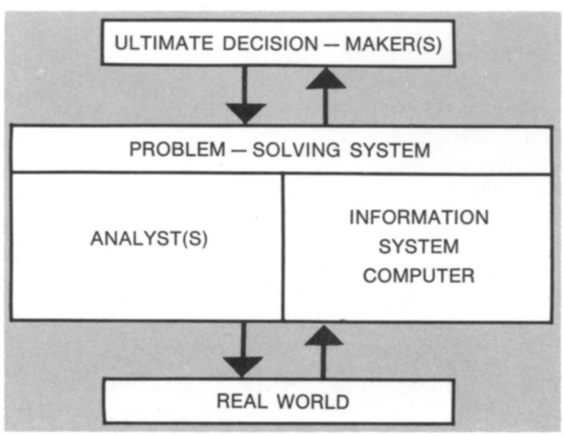
Transportation planning is an example of the very large class of problems Walter Reitman calls "ill-defined,"[3] in contrast to Minsky's definition of "well-defined" problems.[4] The characteristics which are identified here apply as well to urban planning problems and architecture as to other areas of planning and design.

MODEL OF A PROBLEM-SOLVING PROCESS

Data and procedures: The basic elements of a Problem-Solving Process are divided into two major categories parallel to common computer usage: Data and Procedures. The *Data* is what might be represented as "files" in a computer system and includes everything from action to goals. The *Procedures* or "routines," which include procedures for Search, Prediction, Evaluation and Choice, operate upon the files to produce other files.

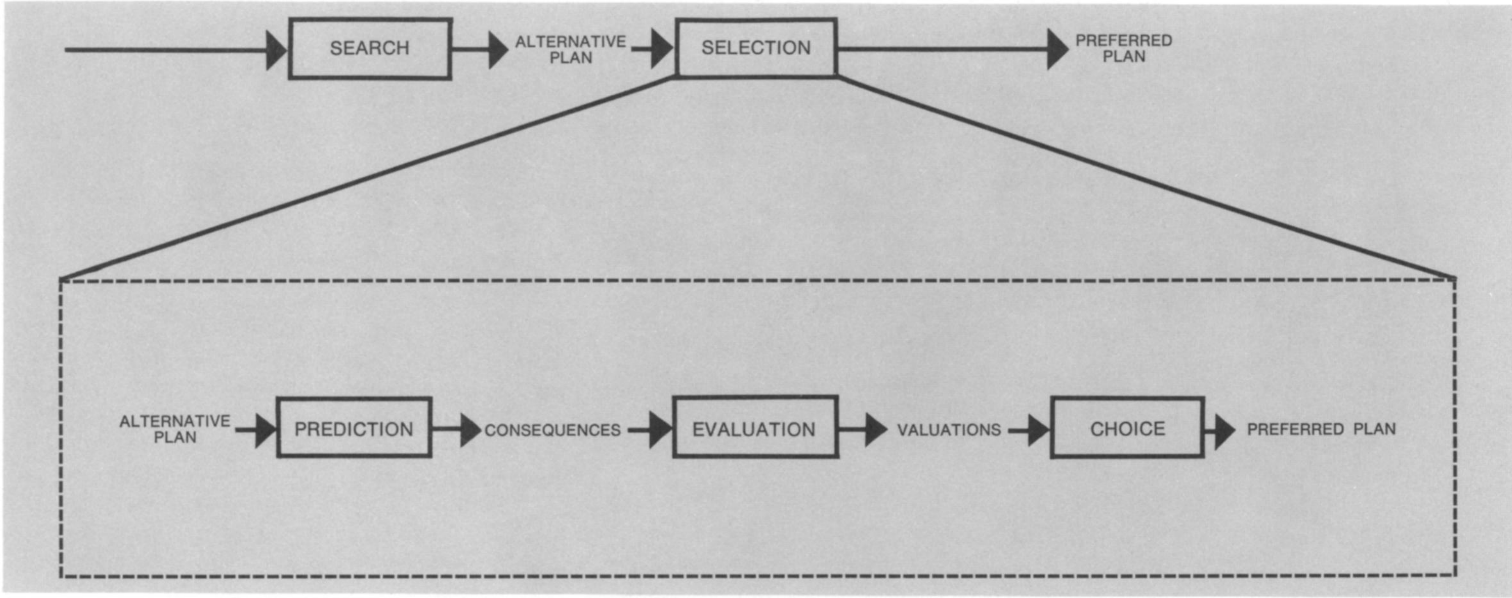
BASIC PROBLEM-SOLVING PROCEDURES

The basic focus of the Problem-Solving Process is on actions which potentially can be implemented in the real world. A Problem-Solving Process concerns the development, selection, implementation, monitoring and revision of actions. The actions may concern building designs, transportation plans, or even economic policies.



A Problem-Solving Process consists of an analyst (the designer or engineer) and the computer system, interacting between the ultimate decision-maker and the real world.

The basic view of the Problem-Solving Process is as follows: Alternative plans or actions are produced, and then a preference ordering over those alternatives is established. If the most desirable alternative is sufficiently attractive, then the Problem-Solving Process ceases and that most desirable action is implemented in the real world. However, if this plan is not sufficiently desirable or attractive, then Search



Basic Problem-Solving Module: The essence of the Problem-Solving Process is that alternative plans of action generated during a Search phase are selected, the consequences of these alternative plans are predicted, evaluated and a choice of the preferred alternative is made.

is repeated and new actions are generated. The sequence is repeated again and again, until finally there is one action sufficiently attractive for implementation in the real world.

This image of a "trial and error" process is basic to this concept of a Problem-Solving Process. Of course, it is completely contrary to the image of a problem for which the optimal solution is obtained directly by "solving" a mathematical model. Such "optimizing" methods correspond to one Search and Selection sequence only and do have an important role in the broader Problem-Solving Process, but as the transportation planning example indicates, real problems are too complex for such techniques to carry the whole burden.

The basic activity of the Problem-Solving Process in any design problem is to produce actions and then choose among them for a solution. The following Search and Selection procedures perform these functions:

Search designates any procedure used to produce one or more alternative plans or actions. Search may be intuitive, as in the sense of "design," or may be formalized, as in a mathematically-formulated problem.

Selection designates the process of choosing among several alternative actions. The input to Selection is a set of alternative actions. The output of Selection is a "preference ordering," or ranking of the actions by desirability. To actually accomplish Selection, three basically different kinds of procedures are required:

a) Prediction: Procedures for Prediction are used to anticipate the consequences which an action would have if implemented in the real world — for example, to predict the reliability and weight of materials in a particular structural design.

b) Evaluation: Procedures for Evaluation operate upon the predicted consequences to yield statements of the valuations, or relative desirabilities of those consequences — for example, the degree to which the structural reliability is satisfactory. All predicted consequences cannot adequately be represented by a single measure of value. For example, costs, safety and aesthetics cannot all be lumped into a single measure of value such as dollars, or some other overall utility measure.

c) Choice: Because of the absence of such a single measure, Evaluation must be followed by Choice. In Choice, each action is compared on the basis of its set of valuations — cost, safety, aesthetic quality, etc. — and then a decision is made about the rankings or preference ordering of the actions.

DATA FILES ASSOCIATED WITH THE BASIC PROBLEM-SOLVING PROCEDURES

There are several types of Data associated with Search and Selection which are filed in the appropriate data files. Each time Search produces new actions, these are added to the data files for action. The current statements of goals relevant to the Problem-Solving Process are stored in the appropriate files. Selection produces data about the consequences of each action, and the valuations of those consequences. The output of Selection is stored in the file containing the latest ranking over the actions.

Search and Selection procedures are used many times in a Problem-Solving Process. Each use results in changes and/or additions to the files for currently open actions, consequences of actions, valuations of those consequences and ranking of actions. To a lesser extent, changes will also occur in the files for goals.

ADDITIONAL PROBLEM-SOLVING PROCEDURES

Because Search and Selection procedures concern the basic generation and selection of actions, these procedures are at the heart of the Problem-Solving Process. But there are a variety of other activities which must occur in a Problem-Solving Process to allow Search and Selection to operate, and to revise the context in which they operate.

Goals are set initially, but may change radically during the operation of the Problem-Solving Process. Consequently, Goal Formulation and revision procedures play an important role.

Information about the state of the real world is continually flowing into the Problem-Solving Process: Information analysis procedures edit and organize this raw data, adding the raw observations to the data base, eliminating actions from the file of currently open actions which are no longer open, providing information to and triggering the goal revision procedures, and revising probability distributions which represent uncertainties. The variables subject to uncertainty are carried in special files, and the current probability distributions over the values of those variables are maintained in other files. These uncertainties are an explicit part of both Prediction and Evaluation and form part of the difficulty of decision in Choice, in that not only the conflicting valuations, but also the explicit uncertainties must be balanced.

Hypothesis generation as well as Calibration and Validation are special procedures which are required to develop the models or plans to be used in Prediction and, to a lesser extent, in Evaluation.

Decomposition and restructuring procedures are concerned with how a problem is broken into subproblems for greater ease in analysis, and how the overall solution is put together from partial solutions to subproblems. For example, in the project of locating a highway, the problem is identified in a list of requirements and a set of interactions which form a tree, a hierarchical listing of subproblems. The overall solution is achieved by first solving the subproblems on the lowest level of the tree and working upward to the top of the tree. For each subproblem, appropriate Search and Selection procedures are required.

Metaprocedures form the overall "executive" of the Problem-Solving Process. At any point in a Problem-Solving Process there are a large number of alternative procedures potentially useful, and a decision must be made as to which procedure to use next. Metaprocedures are used to make this choice. The procedure selected must recognize the fact that resources for problem solving are limited — time, cost and manpower, for instance, are typical constraints.

CONCLUSIONS

A number of principles are basic to this concept of a Problem-Solving Process. These principles should be viewed in their relation to the Problem-Solving Process model.

A Problem-Solving Process involves the application of a variety of different procedures. The basic procedures are Search, Prediction, Evaluation and Choice. The basic procedures of Search and Selection produce the actions, and are iterated many times. Supplemental procedures include Goal Formulation and Revision, Information Analysis, Hypothesis Generation, Decomposition and Restructuring Procedures and Metaprocedures. A full man-machine system for problem solving must possess and make use of all of these types of procedures.

The roles of man and machine will, in general, be different for each procedure in a Problem-Solving Process. A key theme underlying this discussion is the balance between human roles and machine roles in a Problem-Solving Process. The overall objective is to enhance creativity, not stifle it. As Serge Chermayeff put it in describing the myth of conflict between Rationality and Inspiration . . . "Rationality as a system of procedure does not exclude inspiration which acts as an accelerator on the path to the desired goal. Inspiration is a special moment in a rational process. The two are inseparable and complementary."[5]

Nothing in the present model prejudges the balance of roles, once having accepted the fact that we will make use of the computer in some way. There is still great freedom in deciding which aspects of each of the procedures we have identified should be machine-computed, and which require heavy or complete use of human abilities. Roughly speaking, Prediction will make maximum use of the computer, and Choice the least, with Search and Evaluation somewhere between. But the real resolution of this issue will be a personal decision in which the designer always retains the prerogative of using machine-aided procedures or his own intuitive capabilities at each step of the Problem-Solving Process.[6]

Some procedures will be general and applicable to a variety of design and planning problems; others will be more specific and applicable only to a special problem. Prediction procedures will be fairly specific in their application — for example, the prediction of structural behavior of a bridge, or of a sequence of spatial perceptions while driving along a highway. For Search and Evaluation procedures, generality is a matter of degree.

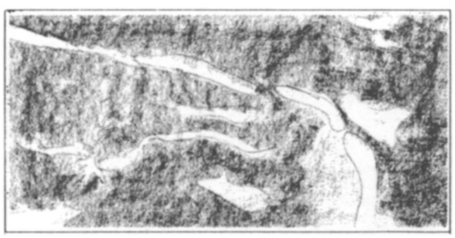
Highway location study: The problem was to locate a twenty-mile stretch of highway in Massachusetts beginning at Springfield and ending near Northampton.

Twenty-six forces or requirements were determined for the location of the highway. Each of these requirements demanded a certain kind of route location (requirement No. 1, for example, "earthwork costs" or *the need to reduce earthwork costs* seeks a highway location through areas where land is flat).

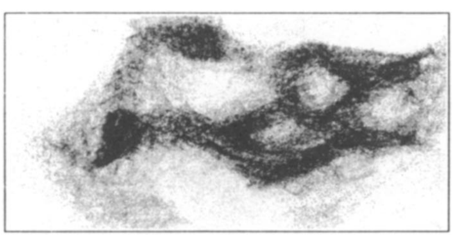
1. **Earthwork Costs.**
2. **Comfort and Safety.**
3. **Regional Development.**
4. **Local Land Development.**
5. **Obsolescence.**
6. **Interference During Construction.**
7. **User Costs.**
8. **Services.**
9. **Travel Time.**
10. **Pavement and Subgrade Costs.**
11. **Drainage Patterns.**
12. **Bridge Costs.**
13. **Land Costs.**
14. **Eyesores.**
15. **Noise.**
16. **Air Pollution.**
17. **Weather Effects.**
18. **Non-Recompensable Public and Private Losses.**
19. **Public Financial Losses.**
20. **Major Current Traffic Desires.**
21. **Catchment Areas.**
22. **Local Accessibility and Integrity.**
23. **Future Transportation Systems.**
24. **Existing Transportation Systems.**
25. **Duplication of Facilities.**
26. **Self-Induced Congestion.**

Twenty-six requirements represented as patterns in shades of gray over the terrain corresponding to the Springfield/Northampton area. Each diagram is a pattern of grays whose density varies over the complete range from white to black. This pattern is keyed to the base map of the terrain in such a way that a point marked black in the diagram for a particular requirement is a very good point for a highway location to pass through (with regard to that requirement).
Any point marked white is very bad as far as that requirement is concerned.

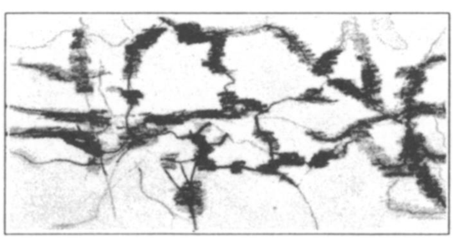
I. EARTHWORK COSTS



2. COMFORT AND SAFETY



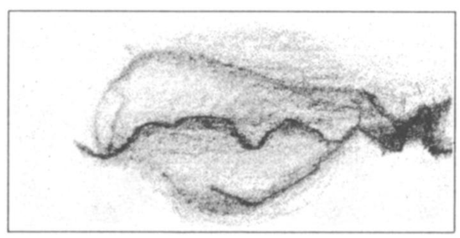
3. REGIONAL DEVELOPMENT



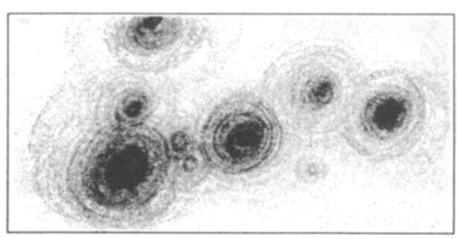
4. LOCAL LAND DEVELOPMENT

5. OBSOLESENCE

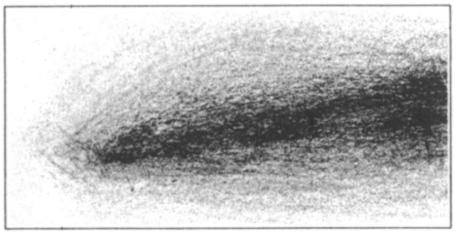
6. INTERFERENCE DURING CONSTRUCTION



7. USER COSTS



8. SERVICES



9. TRAVEL TIME

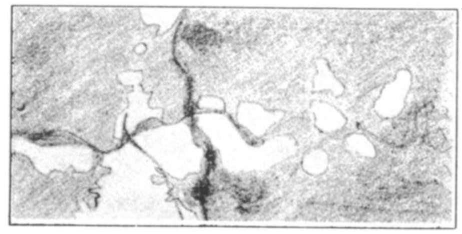
10. PAVEMENT AND SUBGRADE COSTS

11. DRAINAGE PATTERNS

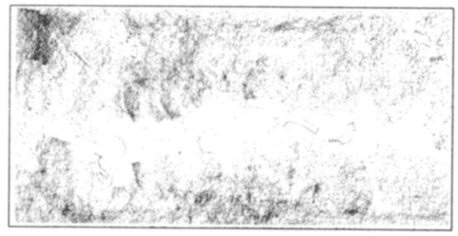
12. BRIDGE COSTS

13. LAND COSTS

14. EYESORES



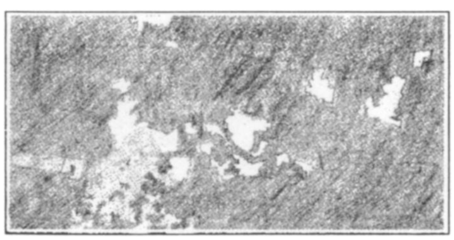
15. NOISE



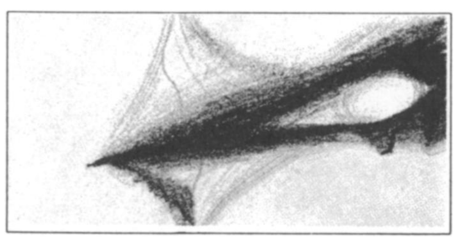
16. AIR POLLUTION

17. WEATHER EFFECTS

18. NON-RECOMPENSABLE PUBLIC AND PRIVATE LOSSES

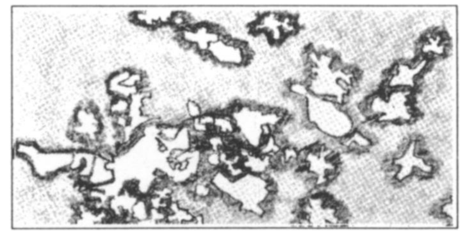


19. PUBLIC FINANCIAL LOSSES

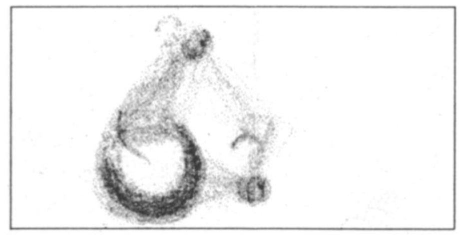


20. MAJOR CURRENT TRAFFIC DESIRES

21. CATCHMENT AREAS

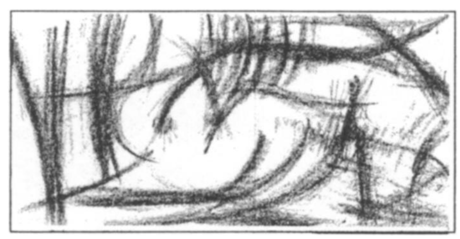


22. LOCAL ACCESSIBILITY AND INTEGRITY

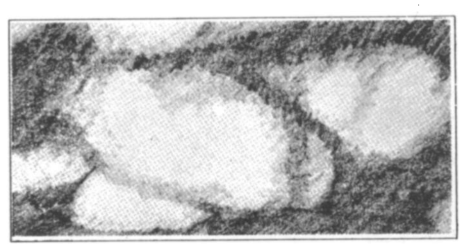


23. FUTURE TRANSPORTATION SYSTEMS

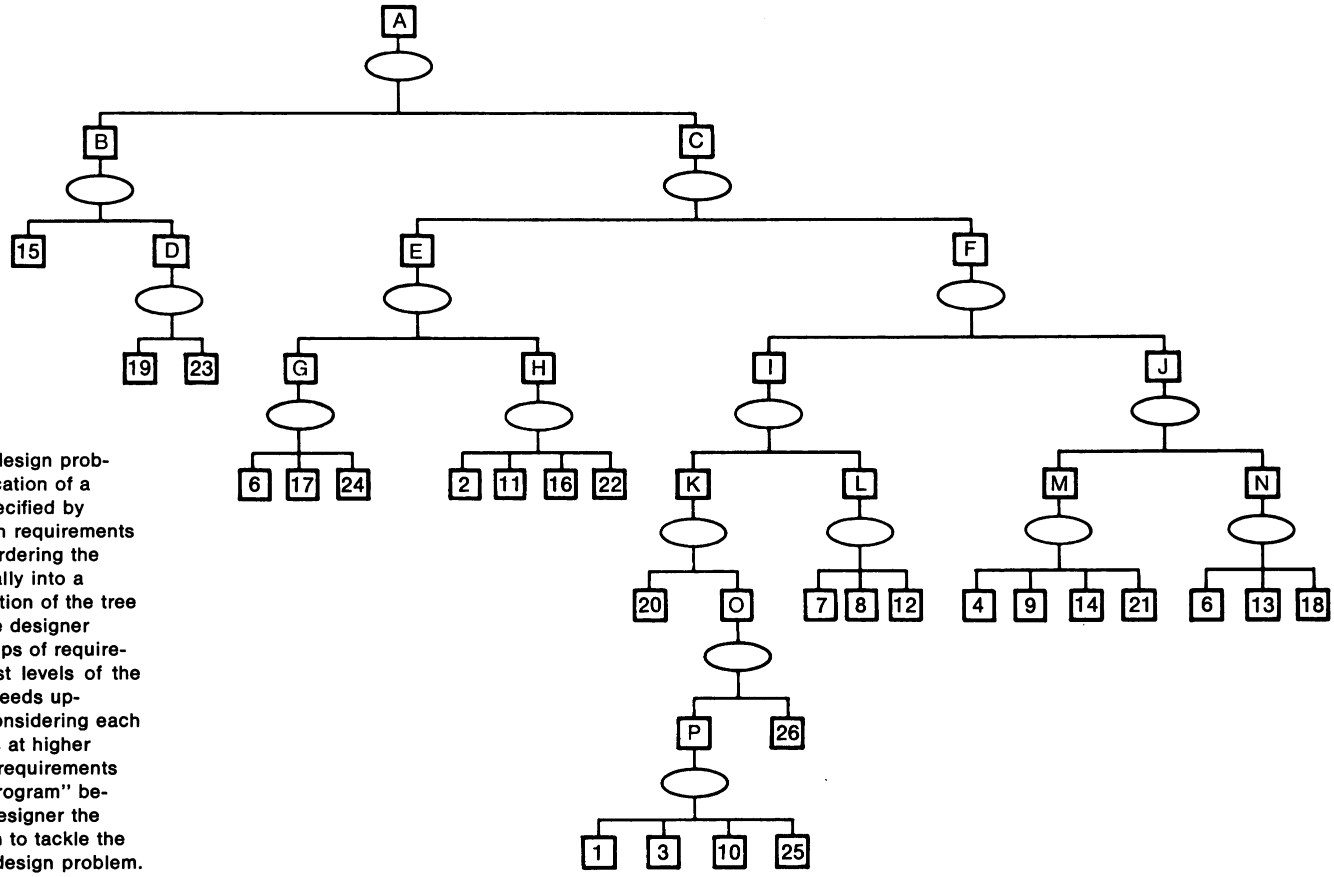
24. EXISTING TRANSPORTATION SYSTEMS



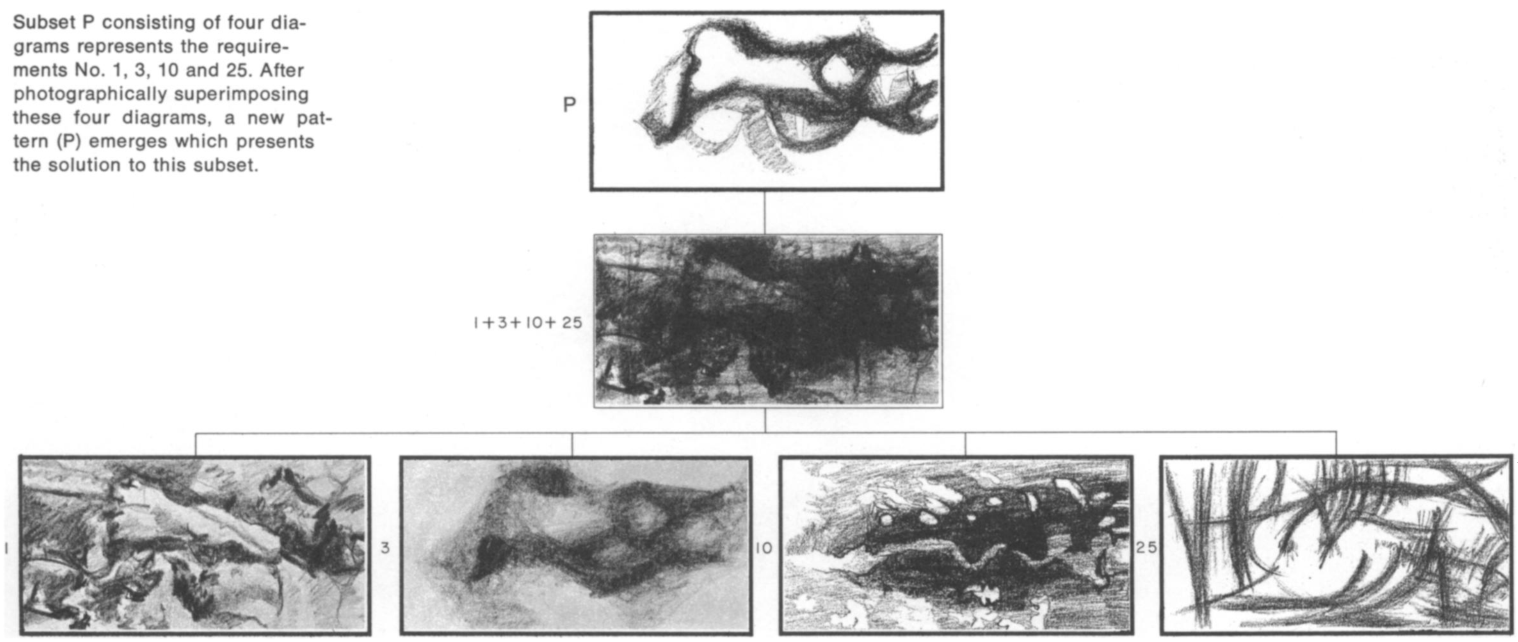
25. DUPLICATION OF FACILITIES



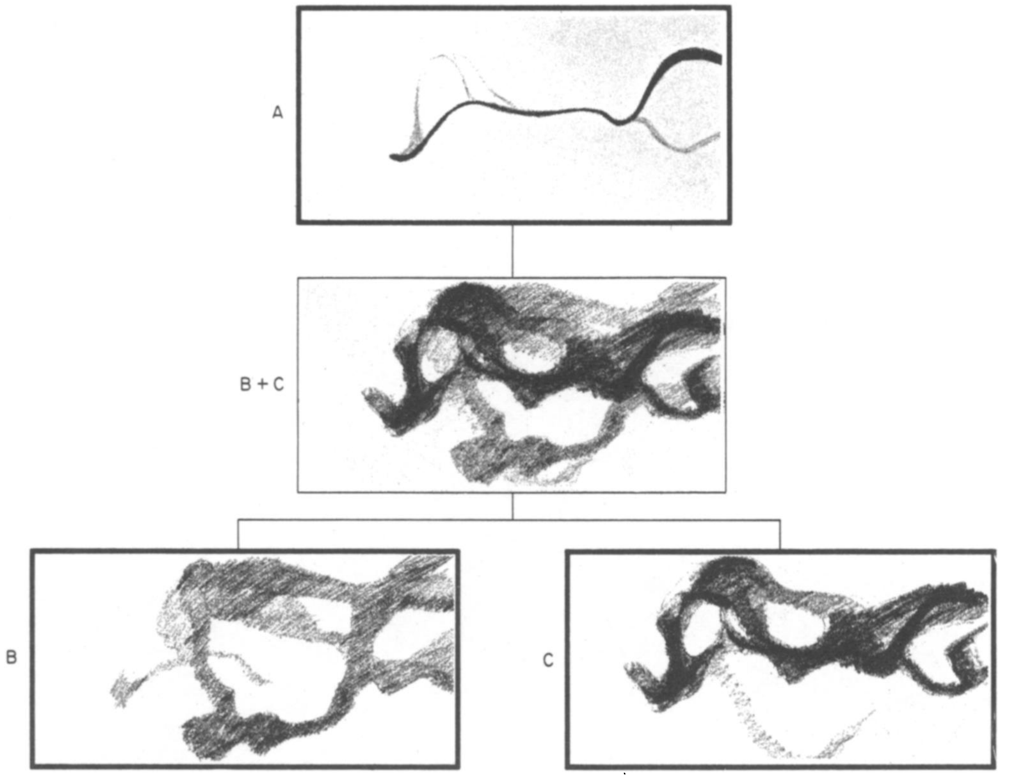
26. SELF-INDUCED CONGESTION



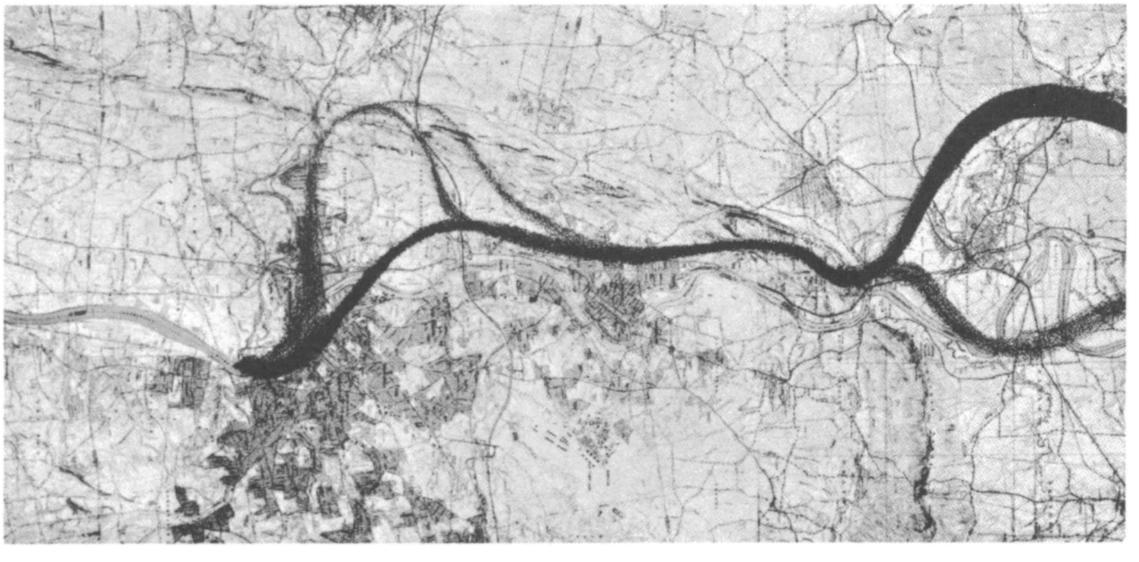
The structure of a design problem such as the location of a highway can be specified by grouping the design requirements into subsets, and ordering the subsets hierarchically into a "tree." The implication of the tree structure is that the designer starts with the groups of requirements at the lowest levels of the tree, and then proceeds upwards, gradually considering each of the other groups at higher levels. The tree of requirements can be called a "program" because it shows a designer the best order in which to tackle the requirements in a design problem.



Subset P consisting of four diagrams represents the requirements No. 1, 3, 10 and 25. After photographically superimposing these four diagrams, a new pattern (P) emerges which presents the solution to this subset.



All subsets in the tree of requirements are solved by superimposition until finally, after a series of fusions, one diagram remains showing only a pair of lines defining the best location for the highway.



The path shown here is the solution to the highway location problem.

There will clearly be some aspects of Search and Evaluation which are specific to a particular problem context; but there are also a number of "service" tools or procedures which can apply to a variety of contexts. For example: hill-climbing and gradient-seeking methods, mathematical programming, and Christopher Alexander's method of hierarchical decomposition are used as Search procedures.[7] In the area of Evaluation, scale construction procedures and many economic formulas will be generally applicable. Procedures for Choice, Metaprocedures, Goal Revision and Information Analysis will all have significant generality and will be transferable from one problem to another. These general procedures can be part of the "service" routines built into an integrated system.

A Problem-Solving Process must be flexible. The sequence of use of the procedures cannot be completely determined in advance, but must adjust as the designer's view of the problem evolves. The designer will continually revise his image of the problem. He will discover new objectives and revise old ones. He will discover that some actions are completely impossible, and he will suddenly invent actions which are radically different from those previously investigated. He also will occasionally discover that his whole approach needs to be discarded.

This model of a Problem-Solving Process explicitly provides for evolution of the designer's view of the problem. This is accomplished through goal revision, model revision, the continual development of new actions, and decomposition and restructuring procedures. Metaprocedures will be provided to determine the procedures to be used as the problem evolves. Particularly important is the ability to use alternative Search and Selection procedures at different levels of detail so that the designer can shift from gross concepts to detailed designing and back again.[8]

The designer cannot obtain an optimal action, only an optimal process. This model of a Problem-Solving Process recognizes explicitly that there is no single criterion for choosing the best action, that generation of actions is difficult, exploration of the full domain of possible actions is completely infeasible, and that determining the desirability of a single action is difficult. Thus, it accepts that the optimal plan or action can never be found. The model recognizes that it is the process of problem solving which is important: one can talk about the optimal allocation of problem-solving resources so that the best action is found within the constraints of the resources and capabilities of the Problem-Solving Process.

Procedures may be executed in sequence or in parallel. The availability of computers which can do many jobs simultaneously through multiprocessors, or through time-sharing, emphasizes the capability to apply procedures in parallel. Some procedures are clearly constrained to sequential relation; Selection can operate only after Search has produced some actions. But most of the procedures may operate in parallel — for example, while Search and Selection are executed, new information may be analyzed, triggering goal revision; at the same time, metaprocedures are operating to compute what should be done after completion of the current Search-Selection iteration.

This qualitative outline of the functions and characteristics necessary in a general Problem-Solving Process still requires a description of specific modules and routines to accomplish the general functions outlined here.

It is expected that this model of a Problem-Solving Process will be substantially revised as time goes on and more knowledge about the structure of a Problem-Solving Process is gained. More research is needed and the application of this Problem-Solving Process should lead to a better understanding of how complex problems can be approached.

REFERENCES

1. Miller, C. L., "An Integrated System for Civil Engineering Design," *Building Research* 3:2 (March-April 1966)
2. Minsky, M., "Steps toward artificial intelligence" in Edward Feigenbaum and Julian Feldman (eds.) *Computers and Thought.* New York: McGraw-Hill (1963), p. 409
3. Reitman, Walter R., *Cognition and Thought.* New York: Wiley (1965), p. 148
4. Minsky, M., op. cit., p. 408
5. Chermayeff, S., *Architecture and the Computer,* the Proceedings of the First Boston Architectural Center Conference, Boston, Mass.: Boston Architectural Center (1964)
6. Manheim, M. L., "The role of the computer in the design process," *Building Research,* 1966, 3:2 (March-April)
7. Alexander, C., *Notes on the Synthesis of Form.* Cambridge, Mass.: Harvard University Press, 1964
8. Manheim, M. L., "Highway Route Location as a Hierarchically-Structured Sequential Decision Process." Research Report R64-15, Cambridge, Mass.: MIT Civil Engineering Systems Laboratory (1964)