RATIONAL LOCATION OF A HIGHWAY CORRIDOR: A PROBABILISTIC APPROACH

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This paper demonstrates a means of considering, through the use of the systems approach and inductive models, the multiplicity of study elements pertinent to the location of a highway corridor. The freeway corridor located in this study was a section of US-77 to and around the city of Lincoln, Nebraska. The study region encompassed areas both of strictly rural character and of intense urban development. Ten different elements for detailed consideration were developed, and each of these elements was modeled in the same manner. Specifically, the structure of each of the individual models was based on how the supply and demand of the study element related to the facility location of least social cost. Least social cost was defined for this study in terms of the resources the people would have to give up to obtain the facility. The quantitative segment of the modeling process was carried out in probabilistic form; that is, both supply and demand were quantitatively stated in terms of probabilities. The result of this modeling technique was that the output of each of the individual models could be used as input to form a composite model yielding the corridor for the facility with the least social cost.

•THE PRIMARY PURPOSE of the highway is to serve, shape, and harmoniously mix with the environment in which it exists. The location of the highway facility should reflect this purpose. Hence, the location of a highway can no longer be selected by simply optimizing items of pertinence only to the highway and those who use it. For example, the problem is not deciding whether waterfowl nesting areas should be preserved or whether a highway should be built. The question has become, How do we do both?

Those involved in the problem of locating highways have come under rather intense criticism from some quarters (1). Through this criticism and recent congressional legislation (2) the location of highways has been given new directions and new dimensions. This means that the techniques, philosophies, and methodologies governing the field of highway location during the "get us out of the mud" era have no place in our present sophisticated, urbanized environment.

The purpose of this paper is to present a new philosophy and methodology of approach that was used in an actual freeway corridor location study.

SYSTEMS PHILOSOPHY

"Expressway development, with all its social, political, economic, and physical ramifications, is so complex that it can only be effectively attacked by new or improved study procedures. As a proven method of solving similar problems, the systems approach is well established in scientific and governmental circles" (3).

A system can be defined as a set of objects or actions that are related in that they combine in an integrated manner to perform a given function. Recognizing this definition, we can easily see that an expressway can be considered as a system. Yet, simply considering an expressway as a system is not a complete description of an expressway's function, because an expressway system is composed of subsystems, each of which is a member of a higher system. Therefore, an expressway is a system that

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exists in an environment and the expressway and its environment mutually affect one another.

The systems approach can be described as a process through which the total examination of a problem area can be undertaken. By formalizing a systems approach, we are attempting to construct a procedure formula that can act simultaneously as a format for input from various disciplines and as a direction of logical progression of a study. The systems approach does not itself guarantee that the resulting analysis of a problem area is going to have more sophistication. It only stresses the need for a "horizontal" or multidisciplinary analysis rather than a "vertical" or single-discipline analysis. By so doing, it is hoped that all relevant elements are considered. The following is a definitive approach to system analysis (3, 4) and is given to indicate and formalize the steps involved in the systems process. Figure 1 shows the steps in the process.

The Lincoln corridor, with which this paper deals, is a part of the expressway-freeway system designated by the state of Nebraska as a long-range development goal. The project objective of the Lincoln corridor study was to determine the most desirable freeway alignment from the vicinity of the present junction south of Lincoln of Neb-33 and US-77 around the west and east portions of the central business district of Lincoln and to determine the most desirable alignment of the extension of K and L Streets westward to an interchange with Interstate 80. The total area within the study limits was approximately 180 square miles (Fig. 2).

Study elements and subsystems for the Lincoln corridor project included the following elements that were associated with the project system environment:

1. Land use—Involving but not limited to agriculture, housing, education, recreation, religion, industry, and commerce;
2. Conservation—Including conservation of wildlife;
3. Community values—Including but not limited to social desires;
4. Public safety—Including evaluation of ease of access to and from hospitals, schools, police stations, and fire houses;
5. Economic activities—Including evaluation facility on economic growth and potential employment;
6. Population—Including growth and spatial trends of the city's population;
7. Compatibility with other plans;
8. Noise, air, and water pollution—Giving special emphasis to schools and hospitals;
9. Public utilities—Including but not limited to the evaluation of impact of facility on major utilities;
10. Natural and historic landmarks—Including evaluation of effects of facility on historic and architectural sities; and
11. Other considerations—Including considerations that become apparent while study is under way.

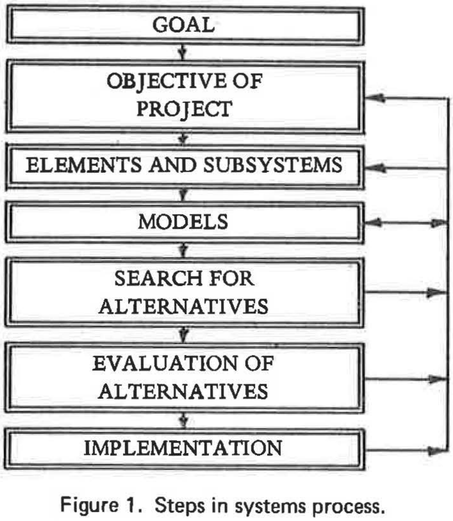

Figure 1. Steps in systems process.

In addition to this partial list of environmental elements to be analyzed was the list of elements describing the study system that had to be dealt with. These included the following:

1. Aesthetics—Including but not limited to conformance of facility with land forms and the view from and to the facility;
2. Cost of facility—Including cost of right-of-way and construction; and
3. Transportation service—Including but not limited to analysis of safety, mode interface, and surface circulation.

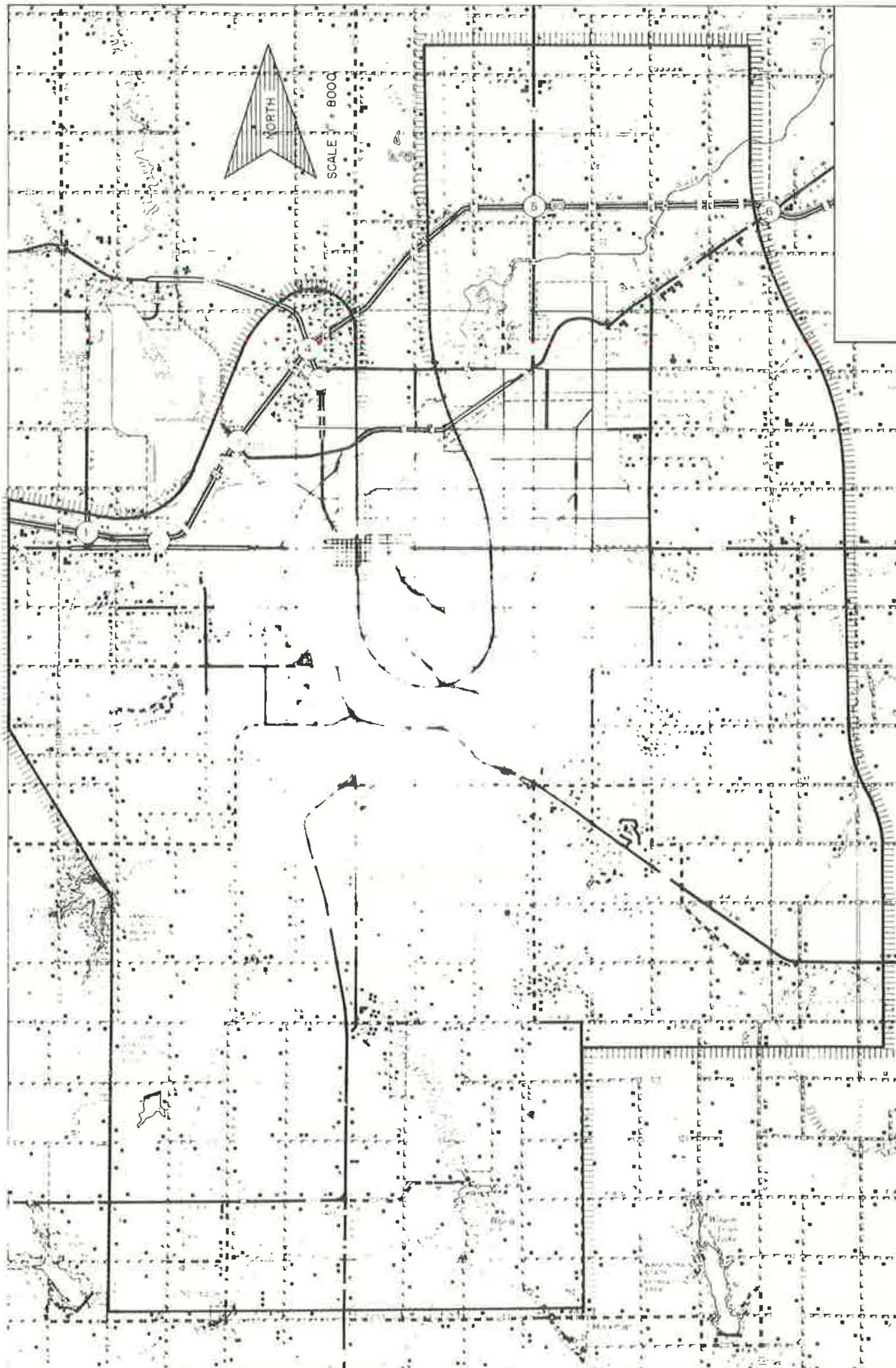

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Figure 2. Study area limits.

In attempting to model these elements, we were confronted with many desires and limitations. One obvious limitation was the inability, through methods such as the common cost-benfit economic analysis or the "shades of gray" method (1), to combine seemingly unrelated items such as vehicle operating costs and social desires. A point of desire was the number of alternatives that we would be able to evaluate through a model. (Intuition told us that the more alternatives we evaluated, the better the chance would be of selecting the best alternative.) What was really desired from the models was the analysis, on a common basis, of the interfaces of the study elements with the study objective.

MODEL PHILOSOPHY AND FORMULATION

The desire was to make the formulation of the models logical to all concerned. This statement was made with the feeling that, if the structure of the models was logical to all, the results of the modeling would have a better chance of being logical to all. What did this desire for logic entail?

If one knows everything about a situation, his knowledge is said to be deterministic. Any question posed to him concerning this situation can be answered by the use of deductive logic. However, situations where all is known are relatively few. A more characteristic situation is one where not everything is known. Answers to questions concerning this type of situation require the use of inductive logic. The characteristic of an inductive logic problem is that not everything is known, yet something is known. An example of a situation where everything is most certainly not known is the problem of selecting the location for a freeway corridor.

If we can conclude that a problem with the characteristics of a freeway corridor study should be analyzed inductively, we must become concerned about what requirements an inductive analysis places on an inquirer. Writers on this topic have made rather elaborate proofs that an inductive analysis should have at least the following criteria (5):

1. Continuity of method—If a problem is solved in a specific way, the method of solution should not change as the numbers or the units on the numbers change;
2. Universality—The analysis base should be universally suitable for any problem;
3. Use of all information—A method should be used that allows the use of all information available; and
4. Use of only unambiguous statements—Every statement of knowledge must be declarative and explicit.

For the models developed for the Lincoln corridor study, we were interested in a model that could follow the list of criteria concerning inductive analysis cited previously and evaluate the largest possible number of alternatives. The second requirement of inductive modeling, universality, requires that all elements be analyzed from the same base. It was felt that analysis in terms of least social cost would be the most advantageous. Least social cost was defined as what people will have to give up in terms of resources to gain the facility. In this way we were able to rate an item as having a "good" chance or a "poor" chance of being of least social cost.

Having selected least social cost as the analysis base and recalling the logic criteria continuity of method and universality, we said that each element of study could be analyzed according to its physical existence and the human desire for that existence. That is, it could be analyzed by its supply and demand. A scarce element having a high human demand is of more relative value than an item of plentiful supply but low demand.

The facility under study would inevitably reduce the physical existence of some of the study elements. If the facility reduced the physical existence of a scarce element for which there was a high human demand, we would have taken something of high social value. The taking of this valuable item would cause the chances or probability of the "take" representing the least social cost to be "poor." On the other hand, if we reduced the existence of an item that was in plentiful supply but of low human demand, the chances or probability of the take representing the least social cost would be "good."

The models used in this study were based on the manner in which the probability of physical existence and the probability of human demand related to least social cost. This method afforded us the ability to maintain continuity of method of analysis of all elements and allowed us universality in that all elements of the analysis had the same units (in other words, they were dimensionless).

In view of the desire to test as many alternatives as possible, it was felt that covering the study area with a link-node grid base and assigning probabilities derived from each model to the grid nodes would afford dense analysis of the study area and, hence, the analysis of a great number of alternative corridors (Fig. 3). The area represented by each node was approximately 800 feet square. The nodes were tied to the state coordinate system.

This procedure amounted to the "prejudging" of the effects that the facility would have on the items existing or planned at closely spaced points in the area covered by the grid. When these probabilities were calculated for all the models over the entire grid, lines connecting the points of highest probability were drawn showing the corridor with the least social cost. The resulting corridor (or corridors) is represented by the optimal alternative out of the hundreds of thousands of alternatives that were analyzed.

DEVELOPMENT OF MODELS

As stated previously, the cost-benefit analysis does not provide a desirable basis for working with an inductive problem. The following simplified example serves the dual role of proof of the previous statement and of example of the modeling technique used in this study.

Consider the following hypothetical case:

Two alternative facilities are to be evaluated by means of the cost-benefit analysis. The costs to be considered include construction costs and right-of-way costs. The benefits are interpreted as travel time saved. Before dollar values are assigned to these elements, it can be said that, if facility 1 has the least construction cost and the maximum travel time saved, it is certain to be the most beneficial. That is, it will have the most desirable cost-benefit ratio. By means of symbolic logic these statements can be recorded as

A_1 = the least construction cost is certain to be facility 1;
B_1 = the maximum travel time saved is certain to be facility 1; and
E_1 = facility 1 is certain to be the most beneficial.

The preceding paragraph indicates knowledge concerning the case that would allow one to automatically, and correctly, assume that facility 1 has the most favorable cost-benefit ratio. Because only two alternatives are being considered and because one can be relatively sure that the two will not have the same cost-benefit ratio, the situation wherein facility 1 would be the most costly can be considered. This situation would occur when construction of facility 1 was certain to be the most costly and when the minimum travel time saved was certain to occur on facility 1.

A_2 = the maximum construction cost is certain to be facility 1;
B_2 = the minimum travel time saved is certain to be facility 1; and
E_2 = facility 1 is certain to be the most costly.

Because this example deals with the evaluation of just two alternatives and because it can be said that facility 1 will in all probability have either the most favorable cost-benefit ratio or the least favorable cost-benefit ratio can it be said that the statement represented by E_1 is the denial of statement E_2? Denial in this case means the assertion of the untruth of a thing stated. To test whether E_1 and E_2 are denials, the following symbolic analysis can be conducted.

$A_1B_1 = E_1$ is symbolically the same as the original statement made concerning the certainty of facility being the most beneficial. The two statements written together are taken to mean that both statements are true. The equal sign means that the two elements on either side have the same truth table. Truth table 1 shown in Figure 4 indicates what has already been said; A_1 and B_1 both have to be true to make E_1 true.

Now, consider the second situation, where facility 1 is certain to be the most costly, and proceeding as in the foregoing (Fig. 4, truth table 2).

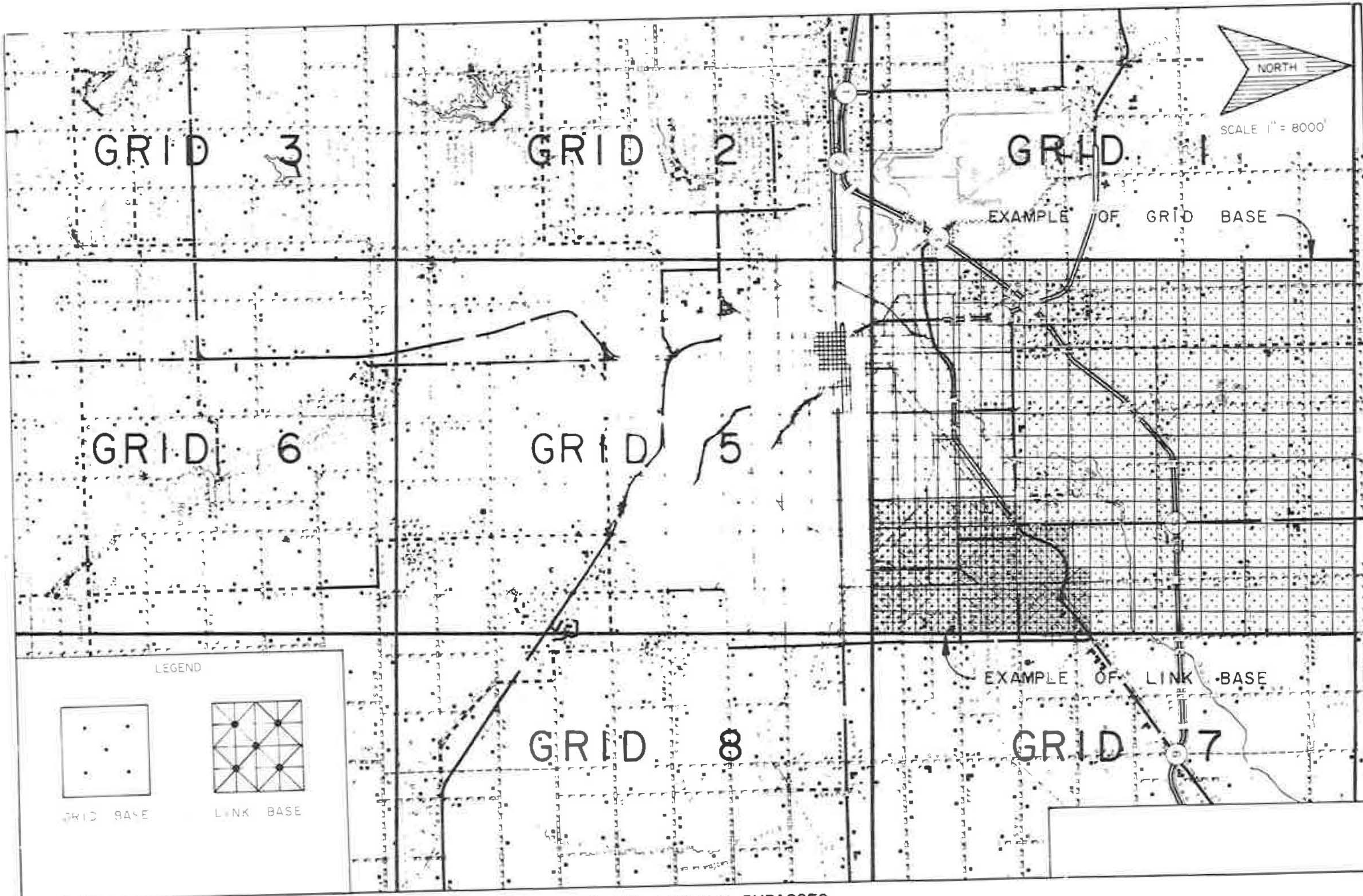

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Figure 3. Link-node grid base.

$A_1B_1 = E_1$

	A_1	B_1	E_1
1	T	T	T
2	F	T	F
3	T	F	F
4	F	F	F

Truth Table No. 1

$A_2B_2 = E_2$

	A_2	B_2	E_2
1	T	T	T
2	F	T	F
3	T	F	F
4	F	F	F

Truth Table No. 2

	E_1	E_2
1	T	T
2	F	F
3	F	F
4	F	F

Truth Table No. 3

Figure 4. Truth tables for hypothetical case.

In order for E_1 and E_2 to be denials of each other, they must have opposite truth tables. This is not the case, because they have the same truth table (Fig. 4, truth table 3).

For a more detailed discussion of the use of truth tables and denials, the reader is referred to the work by Tribus (5).

It can be seen through this example that inductively cost and benefit are not denials of each other. That is, an item is not either a cost or a benefit. The denial of statement E_1 is e_1, which is that facility 1 is not certain to be the most beneficial. Another way to indicate this lack of relationship is that the denial of A_1 and B_1 are the same in these two alternative examples as the statements A_1 and B_2 yet the logic statements $A_1B_1 = E_1$ and $A_2B_2 = E_2$ are not denials of each other.

Again taking the preceding example, assume that we want to guess whether facility 1 is certain to be the most beneficial. Statement A_1 in this case is either true or false, and, because we have no other knowledge that would indicate any other action, we can say that the chance or probability of A_1 being true is $\frac{1}{2}$. (One way of deciding whether A_1 is true is to place the letter T on one side of a coin and the letter F on the other and flip the coin.) Likewise, consider B_1 to have a probability of $\frac{1}{2}$. The probability of E_1 being true could then be calculated (5).

$$P(A_1B_1/E_1) = \tfrac{1}{2} \times \tfrac{1}{2} = \tfrac{1}{4}$$

or denial,

$$P(a_1 + b_1/e_1) = \tfrac{1}{2} + \tfrac{1}{2} - \tfrac{1}{4} = \tfrac{3}{4}$$

Note: Recall that $A_1B_1 = E_1$ means that statement A_1 and statement B_1 have the same truth table as statement E_1, then "$P(A_1B_1/E_1)$ means that the probability of the truth of statement A_1 and statement B_1 is conditional on the truth of statement E_1" (5). Further, recall that $a_1 + b_1 = e_1$ means that statement a_1 or statement b_1 or both statement a_1 and statement b_1 have the same truth table as statement e_1, then $P(a_1 + b_1/e_1)$ means that the probability of the truth of statement a_1 or the truth of statement b_1 or the truth of both statements a_1 and b_1 is conditional on the truth of statement e_1. It should be noted still further that $P(A_1/E_1) + P(a_1/E_1) = 1.0$.

If we know A_1 to be true, its probability becomes 1.0. The probability of E_1 being true is

$$P(A_1B_1/E_1) = P(A_1/E_1)\,P(B_1/E_1) = 1 \times \tfrac{1}{2} = \tfrac{1}{2}$$

or denial,

$$P(a_1 + b_1/e_1) = 0 + \tfrac{1}{2} - 0 = \tfrac{1}{2}$$

If we know A_1 and B_1 to be true, their probability each becomes 1.0, and the probability of E_1 being true is

$$P(A_1B_1/E_1) = P(A_1/E_1)P(B_1/E_1) = 1 \times 1 = 1$$

or denial,

$$P(a_1 + b_1/e_1) = 0 + 0 - 0 = 0$$

Note: As the number $P(A_1B_1E_1)$ increases in value, the statement A_1B_1 is becoming more credible relative to its denial $a_1 + b_1$.

If we know A_1 to be true, its probability becomes 1.0. Further, if one assumes that B_1 is not true, its probability becomes 0. The probability of E_1 being true is

$$P(A_1B_1/E_1) = P(A_1/E_1)P(B_1/E_1) = 1.0 \times 0 = 0$$

or denial,

$$P(a_1 + b_1/e_1) = 0 + 1.0 + 0 = 1.0$$

This indicates that E_1 is not true. It has been said that facility 1 is the least costly in terms of construction but has the least travel time saved. Hence, E_1 (facility 1 is certain to be the most beneficial) is false. In point of fact, E_1 will always be false even though it may have a favorable cost-benefit ratio.

What this indicated is that both statements A_1 and B_1 must be true before we can be certain that E_1 is true. Therein rests the difficulty inherent in the cost-benefit ratio; it is deterministic, and it is based on deductive logic. Hence, it has little application to a situation such as highway corridor evaluation that requires inductive logic.

Of importance in this example is the demonstration that one can initially set numerical values to statements and test their relationship to that statement's denial, and that it is necessary in inductive analysis to work from a single base. That is, we must either work from a basis of cost, a basis of benefit, or some basis between the two. The basis for this study, as indicated in the preceding text, was least social cost. The reason for the selection of this base was simply that it did not have the ambiguity of other choices.

As has been indicated, least social cost was thought of in terms of supply and demand. One could think of supply in the sense of physical existence and demand in the sense of human desire for that existence. Existence and desire were assumed to be independent of each other.

It should be mentioned here that statements concerning least social cost varied depending on whether the element being modeled was an environmental element or a system element. This difference was largely one of what we would like the facility to do and what we would like the facility not to do. We have defined least social cost as what people will have to give up in terms of resources to gain the facility. Regarding the facility's effects on the environment, it was said that one would like to take the least amount of resources. Defining resource in terms of supply and demand, what we preferred to take was something of abundance for which little desire exists.

The systems model was the reverse of the preceding one, because here one would prefer to take something that was in little existence but for which there was a high demand. For instance, it was quite important for the facility under study to interchange with other existing and planned facilities. As the existence of good interchange locations decreased, it became more important to "hit" these locations.

The basic philosophy behind the development and structure for all the models was consistency—consistency in the depth to which each element was modeled and the consistency in terms of elements modeled. The great temptation for one who specialized in transportation was to over-model his specialty. This would have biased the cumulative model toward this discipline.

The following is a description of the models used in this study. The description includes both a statement of philosophy behind the model and, for two of the models, the symbolic logic of the model's structure.

Agriculture

The purpose of the agricultural model was to establish the corridor of the facility under study that had the least social cost with regard to agricultural activity. This model, as were all the models, was developed on the basis of supply and demand. With supply and demand as a basis, one could think of agriculture as an activity where the farmers' highest demand was for an acreage with the highest yield (on a protein basis or dollar-return basis). It was further assumed that the lowest demand would be for the acreage with the lowest yield and that, between these extremes, demand would continually relate directly with acreage yield (6).

In the foregoing paragraph it was stated that demand was based on yield, but because yield bore nearly a direct relationship with soil type, it was also possible to think of demand being based on soil type. This was a particularly important relationship in view of the fact that soil classification information was readily attainable, whereas yield or production information was not.

We could think of agricultural demand as the relative desire of the farmers to own a certain acreage. Based on the soil type, we could also think of agricultural supply as being the relative physical existence of certain yield classes of soil types. Table 1 gives the acre yield-soil type group classification used in this study (7).

Having stressed the preceding relationships, it was necessary to define what these meant in terms of least social cost. For instance, one could say that an acre yield-soil type having a high probability of existence (high supply) for which a low desire (low probability of demand) existed was of low value. On the other hand, an acre yield-soil group having a low probability of existence but a high demand could be recognized as being of high value. From this premise, therefore, it would be of least social cost from the farmer's point of view to have the facility take the land having an acre yield-soil group of low value.

Specifically, it was said that, in terms of least social cost to agriculture, one would prefer to take land that has an acre yield-soil group that was in plentiful supply but for which a low desire existed. With this basis one would be certain to have the least social cost for the take of agricultural land if the physical existence of a soil group throughout the study area was uniform (i.e., no other groups exist) and if no desire exists for that soil group. This premise was universal in the environmental models. Symbolically this was shown as follows:

A = physical existence of soil group;
B = no desire for soil group; and
E = least social cost for the take of agricultural land.

Recalling that AB means statement A and statement B, we can symbolize the statements AB = E.

The probability statement of this relationship was proved to be $P(AB/E) = P(A/E)P(B/E)$. To demonstrate this probability statement, we used the foregoing example. If no other soil group existed, the probability of finding only the group that does exist is 1.0. If no desire for this soil group exists, the probability of finding no desire for this group was 1.0. Hence, $P(AB/E) = P(A/E)P(B/E) = 1.0 \times 1.0 = 1$, which indicates that this situation represents a 1.0 probability of being the least social cost for the take of agricultural land.

It was known, of course, that more than one soil group existed in the study area. It was also known that all soil types were of some demand. However, the foregoing example demonstrates the basis for the development of this model.

The symbolic statement for group 1 soil types of the agricultural model is as follows:

$$A_{1a}B_{1a} = E_a$$

$$P(A_{1a}B_{1a}/E_a) = P(A_{1a}/E_a)P(B_{1a}/E_a)$$

TABLE 1

AGRICULTURAL SOIL CLASSIFICATION

Soil Group	Crop	Yield (high, medium, low)
1	Corn, wheat	H, H
2	Corn, wheat, and sorghum	M, H
3	Sorghum, grass	M, H
4	Sorghum, grass	L, M
5	Grass	L
6	Sedge	—

where

A_{1a} = physical existence of group 1 soil types;
B_{1a} = no human desire for group 1 soil types; and
E_a = least social cost for take of agricultural land.

Similar statements were made for the four other groups of soil types. The results of these probability calculations are given in Table 2. Group 3 has the highest probability of least social cost.

TABLE 2

PROBABILITY OF LEAST SOCIAL COST FOR TAKE OF AGRICULTURAL LAND

Soil Group	Probability of Supply	Probability of No Demand	Probability of Least Social Cost
1	0.21	0.05	0.0105
2	0.42	0.25	0.105
3	0.31	0.50	0.155
4	0.05	0.75	0.0375
5	0.01	0.95	0.0095

Noise

The purpose of the noise model was to establish the corridor of the facility under study that had the least social cost with regard to noise creation. In this model the premise of supply and demand was thought of in terms of noise creation or generation as the supply function and the discomfort of various noise levels as the no-demand function. Three documented relationships allowed one to predict levels of noise and the discomfort related to this noise. These three relationships were (a) distribution of noise-generation level at edge of roadway; (b) abatement of noise with distance; and (c) distribution of human discomfort with noise level (8, 9).

The actual technique used involved the following steps:

1. Defining boundaries or present development;
2. Identifying the land use of these areas;
3. Defining boundaries of future developments;
4. Defining the probability that noise will not be above the 60-dB limit within the boundaries of development; and
5. Defining the probability that noise will not be above 60 dB in progressive spatial steps away from the development boundary (with the number of steps assigned varying according to land use).

Replacement

One of the most difficult items of consideration in this corridor study was the effects the facility would have on development. We were specifically concerned with the abundance and location of adequate replacements if the facility were to take a certain type of development. Even further in this same regard, we were concerned with the desire of those who might be moved (10). The basis for the development of a model reflecting relocation considerations rested in thinking of supply as being the quantity of replacement development available and of desire for this supply of replacement development as being demand. The replacement model constructed herein included the analysis of relocation of the following types of development: industrial; commercial; residential; and other types such as recreation, institutions, schools, and cemeteries.

Optimum Land Conditions for Development

The purpose of the optimum land conditions model was to relate the facility under study to the most favorable soil and subsoil characteristics as viewed from the standpoint of future development. A hierarchy of five land condition groups were developed (11), and their existence within the study area was analyzed thereby determining the probability of occurrence (supply). The demand segment of the model was the expression of desire for each type of land condition.

Interference

In order to seek a corridor location with the least social cost, effects of interference of the facility with such items as boundaries, lines, and established routes had to be analyzed. Included in such an analysis were things such as neighborhood and personal property boundaries, police districts, fire districts, school bus routes, and utility lines. The number of lines, boundaries, and routes crossed by the four links leading to a forward node were recorded and assigned to that node. This was done for each of the nodes in the study area. The supply probability was determined from the chance of finding an existence of each of the numerical groups. The demand probability was, as before, developed on the basis of relationship to the physical existence hierarchy.

Conservation

The effects of the facility on conservation and animal ecology were deemed of high importance in the selection of a corridor location. The method of determination of supply groups was by the interspersing of cover types. With this method, one worked with a standard land area, such as a section, and counted the number of cover interfaces; that is, the number of changes from grass, crop, and woodland along the diagonals of the standard area. The higher the number of interfaces in a given area were, the more valuable was the area of wildlife. This information base was the result of work done by the Nebraska Game and Parks Department. In accordance with the universal development of the models used here, the probability of existence of the interface groupings was determined. The desire for each of these groupings was found to vary directly with the cover interference hierarchy.

Aesthetics

There were, according to specialists in the field (12, 13), three elements of primary concern in the aesthetic design or location of the facility. These elements were (a) conformity of the facility with ground contours, (b) conformity of the facility with vistas viewed from the road, and (c) view of the facility itself. The aesthetics model was the first of what was termed the systems model. That is, it modeled what one would like to have the facility accomplish. The previous six models were statements of what one would not like to have the facility do. This designation was important because it affected the structure of the logic statements and the resulting mathematics. The general approach, however, remained the same.

The first step in the generation of this model was the determination of the probability of finding conformity of contours and direction of facility. The grouping of this conformity was done as shown in Figure 5. Each zone in the study area was categorized in this manner, and the probability of finding each of these 3 conformity categories was determined. The desire for each of the categories was assumed to relate directly to the degree of conformity. Because of the general magnitude of the relief in the study area, it was assumed that degrees of differences of the desires for each of these categories would not be great. The two remaining elements, the view to road and the view

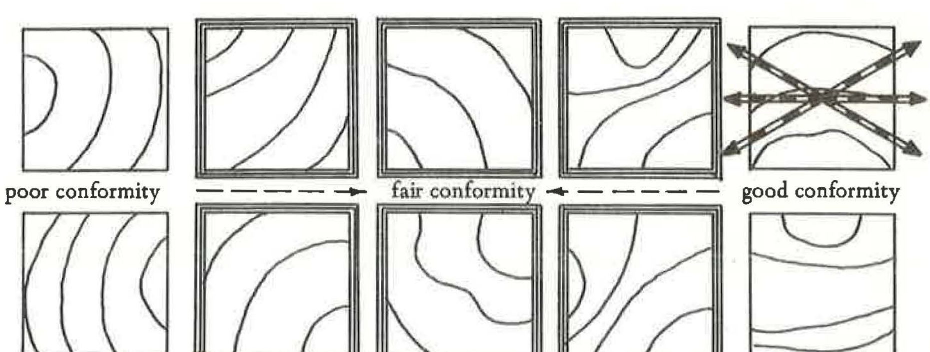

Figure 5. Conformity categories for aesthetics hierarchy.

from road, were analyzed as to areas of significance and were coded into the model in accordance with the previously stated rules of inductive model building.

The symbolic statement of this model is as follows for group 1 conformation types:

$$A_{1h}B_{1h} = E_h$$

$$P(A_{1h}B_{1h}/E_h) = P(A_{1h}/E_h)\,P(B_{1h}/E_h)$$

where

A_{1h} = no physical existence of group 1 conformation types;
B_{1h} = human desire for group 1 conformation types; and
E_h = east social cost for aesthetic conformation.

Similar statements were made for the other two groups of conformation types.

In addition, the following are considerations for good from road view and poor to road view:

$$A_{nh}B_{nh}D_h + C_h = E_h$$

$$P(A_{nh}B_{nh}D_h + C_h/E_h) = P(A_{nh}B_{nh}D_h/E_h) + P(C_h/E_h)$$

$$- P(A_{nh}B_{nh}D_n/E_n)\,P(C_h/E_h)$$

where

C_h = from road view, and
D_h = to road view.

Facility Cost

One of the basic elements of concern in defining the corridor location was the ultimate cost of the facility, because minimizing the cost of the facility certainly was of concern even in terms of a least social cost analysis. The development of the cost model was predicated on the fact that certain land use and topographic characteristics will innately generate certain ranges of facility cost. As before, the probability of occurrence of each of the categories was determined. The desirability of each of these categories was assumed to be directly related to the facility cost hierarchy and to follow a normal curve.

Travel Desire

Travel desire pertained to the existence of the facility and the desire for the use of that facility in the manner for which it was intended; that is, travel. In the development of the travel desire model, we were concerned with the direction of the travel desire and the magnitude of that desire by direction. However, encoding of pure numbers, such as magnitude of travel desire, was not in keeping with the requirement of universality. Hence, the percentage of total volume rather than simple volume was used. This allowed one to speak in terms of the probability of travel desire by direction. This probability was the statement of facility travel demand. Because this was a systems model and in keeping with the generalized statement that systems supply was related to no physical existence, the probability of "no physical existence of the facility" was assumed to be 1.0. In other words, the facility was assumed not to exist.

Mode Interface

In order for the facility under study to operate correctly, it was necessary to study how the facility would interact with the present and planned street and highway system and with the other forms or modes of travel. The actual technique used in the development of the mode interface model consisted of spotting locations throughout the study area of particular importance to the ultimate manner in which the facility would integrate into the total travel system of the region. These locations so designated were placed in a hierarchy, and the supply and demand probabilities were determined in the manner universal to all models.

Composite

As indicated in the symbolic statement of each of the models, the location of least social cost for each item of consideration has been established. In short, the location has been optimized from various points of view. It must be stated that one cannot optimize each of several elements and then simply put them together and come out with an optimized interaction of all of the elements. What must be done is to combine all of the statements of least social cost at a node in the same manner that was used in reaching that statement in each of the models. This follows the continuity criteria of inductive model development and results in an optimized interrelationship of elements rather than a collection of optimized elements.

The following is the symbolic statement of the composite or project model:

$$P(E_aE_bE_cE_dE_eE_fE_gE_hE_iE_jE_k/E_p) = P(E_a/E_p)P(E_b/E_p)P(E_c/E_p)P(E_d/E_p)$$
$$P(E_e/E_p)P(E_f/E_p)P(E_g/E_p)P(E_h/E_p)$$
$$P(E_i/E_p)P(E_j/E_p)P(E_k/E_p)$$

where

E_a = least social cost for take of agricultural land;
E_b = least social cost for creation of noise;
E_c = least social cost of replacement;
E_d = least social cost for optimum land;
E_e = least social cost for interference with lines and boundaries;
E_f = least social cost of conservation interference;
E_g = least social cost for take of other elements;
E_h = least social cost for aesthetic conformation;
E_i = least social cost for facility costs;
E_j = least social cost for travel desires;
E_k = least social cost for mode interface; and
E_p = least social cost for project model.

RESULTS

As has been stated, the desire of this methodology was to prejudge the effect of the facility in question at a large number of points spaced throughout the study area. To accomplish this, a quantitative statement of least social cost, in terms of probability, was made for each of the models at each of the grid nodes.

Having 10 models and 7,500 points, this meant that 75,000 statements of least social cost were generated. Because this information had to be retained and because 75,000 calculations were necessary in the accumulative model, a file and computation program was written for the IBM 1130 computer. The program was written in such a manner as to make the file of each model individually retrievable so that correction or updating could be carried out with a minimum of interference and delay.

The results of the modeling process, as represented in the accumulative model, consisted of 7,500 statements of probability of least social cost, one for each node. The range of these resultant probabilities was from 2.0×10^{-3} to 8.0×10^{-15}. Each of these probabilities, in a coded form, was placed on a 2,000 scale U. S. Geologic Survey map of the study at a point corresponding to the respective nodes. The resulting pattern is

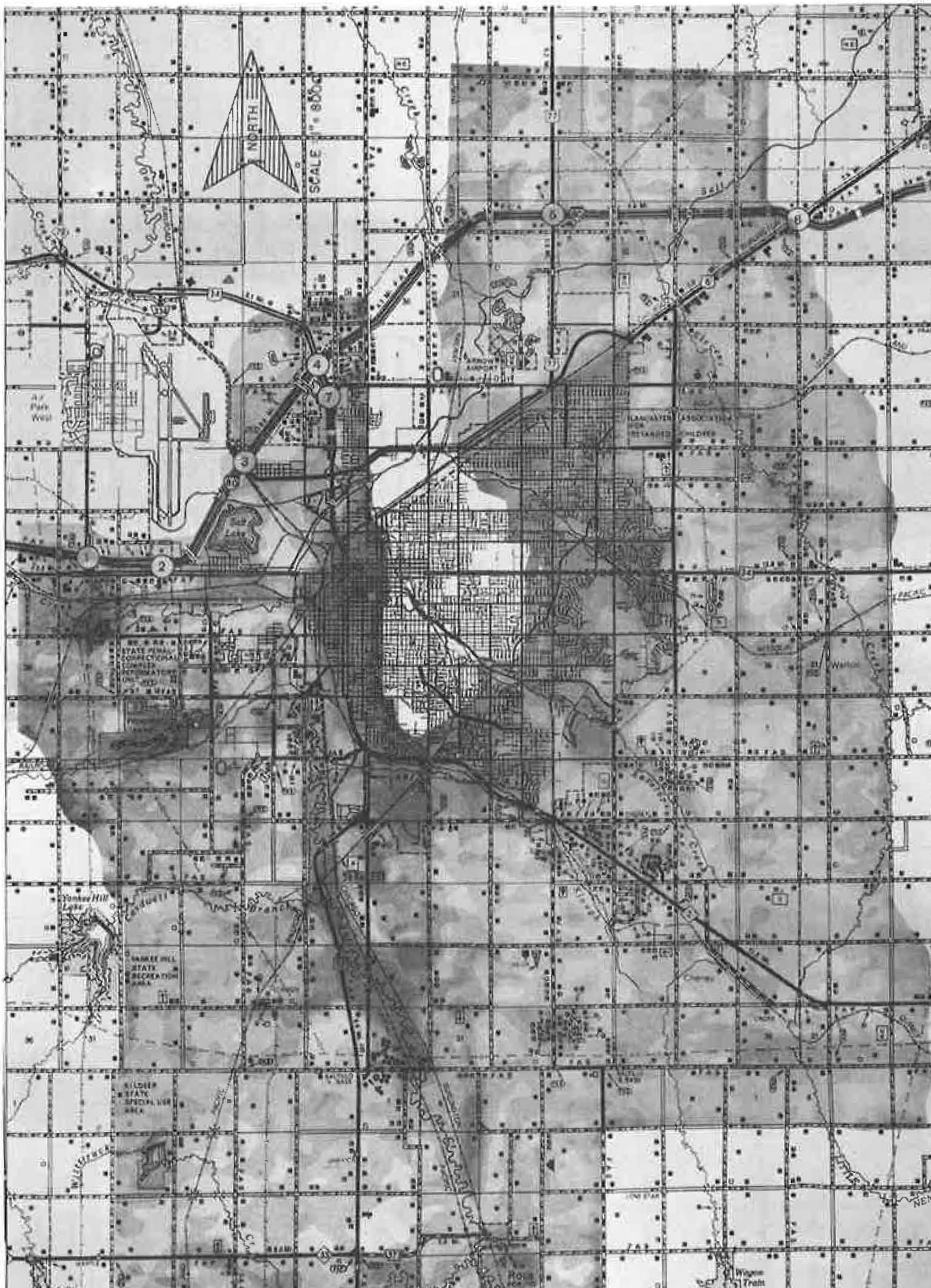

Figure 6. Composite model.

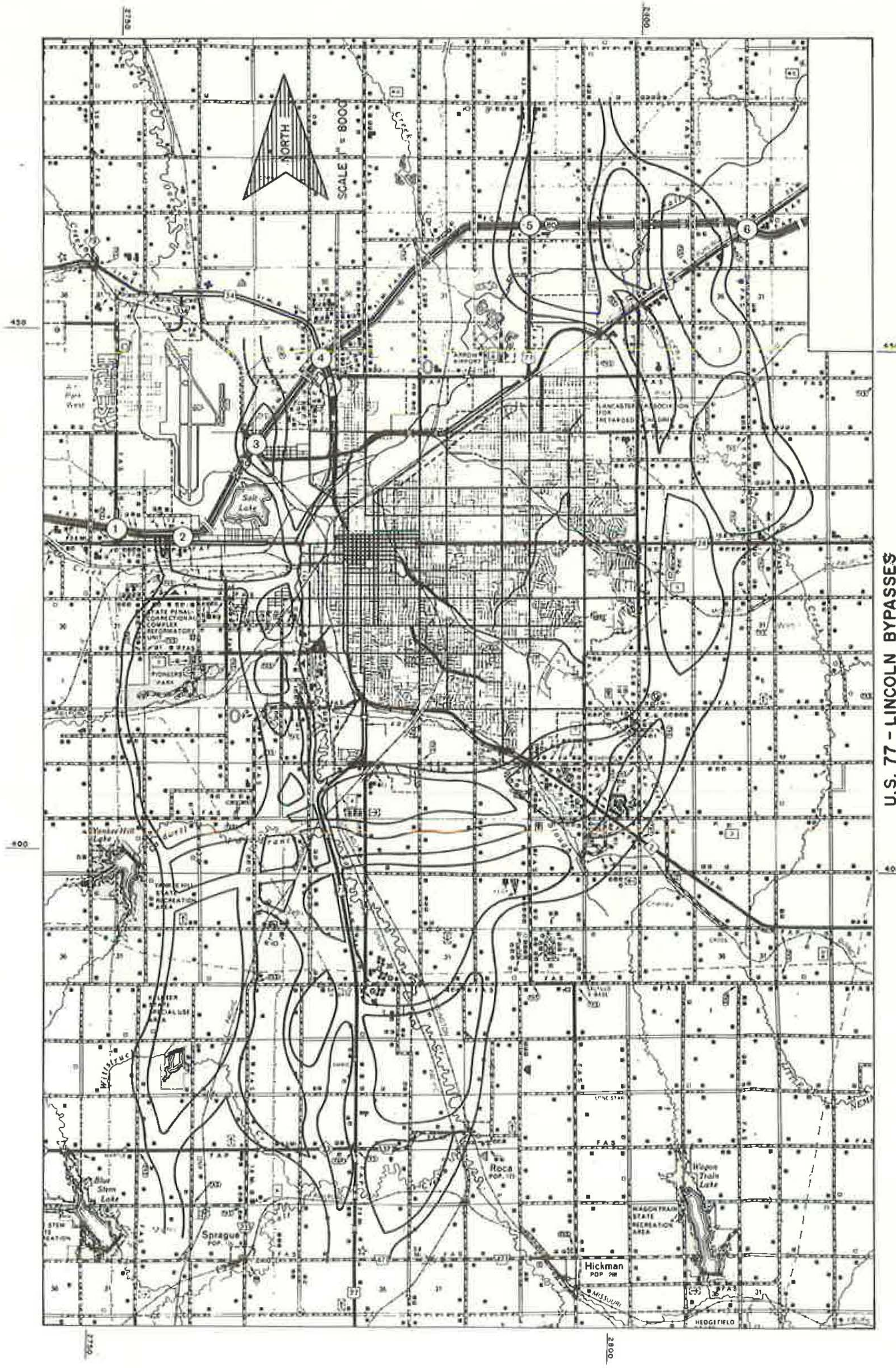

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Figure 7. Corridors for analysis.

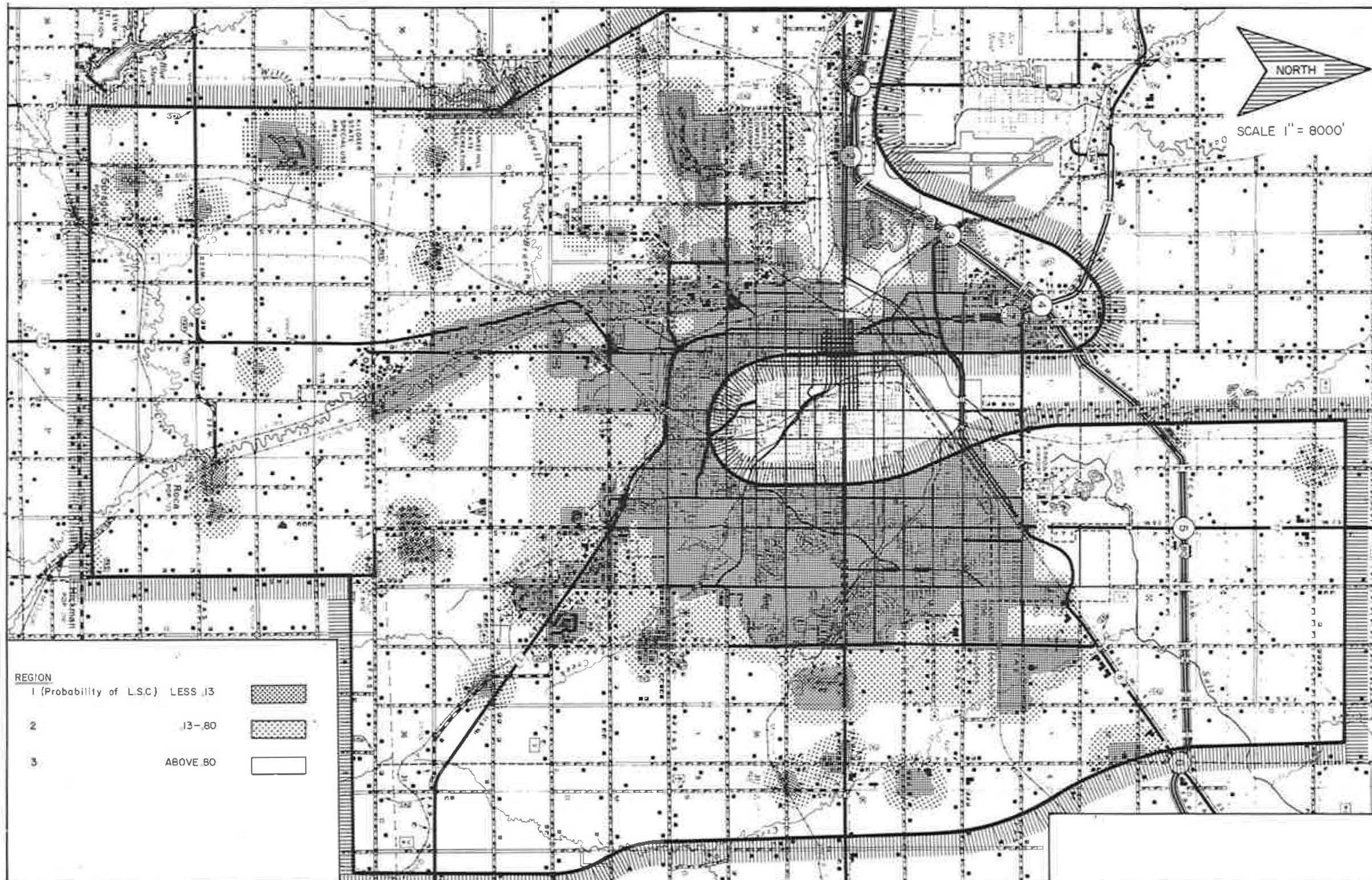

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Figure 8. Noise model.

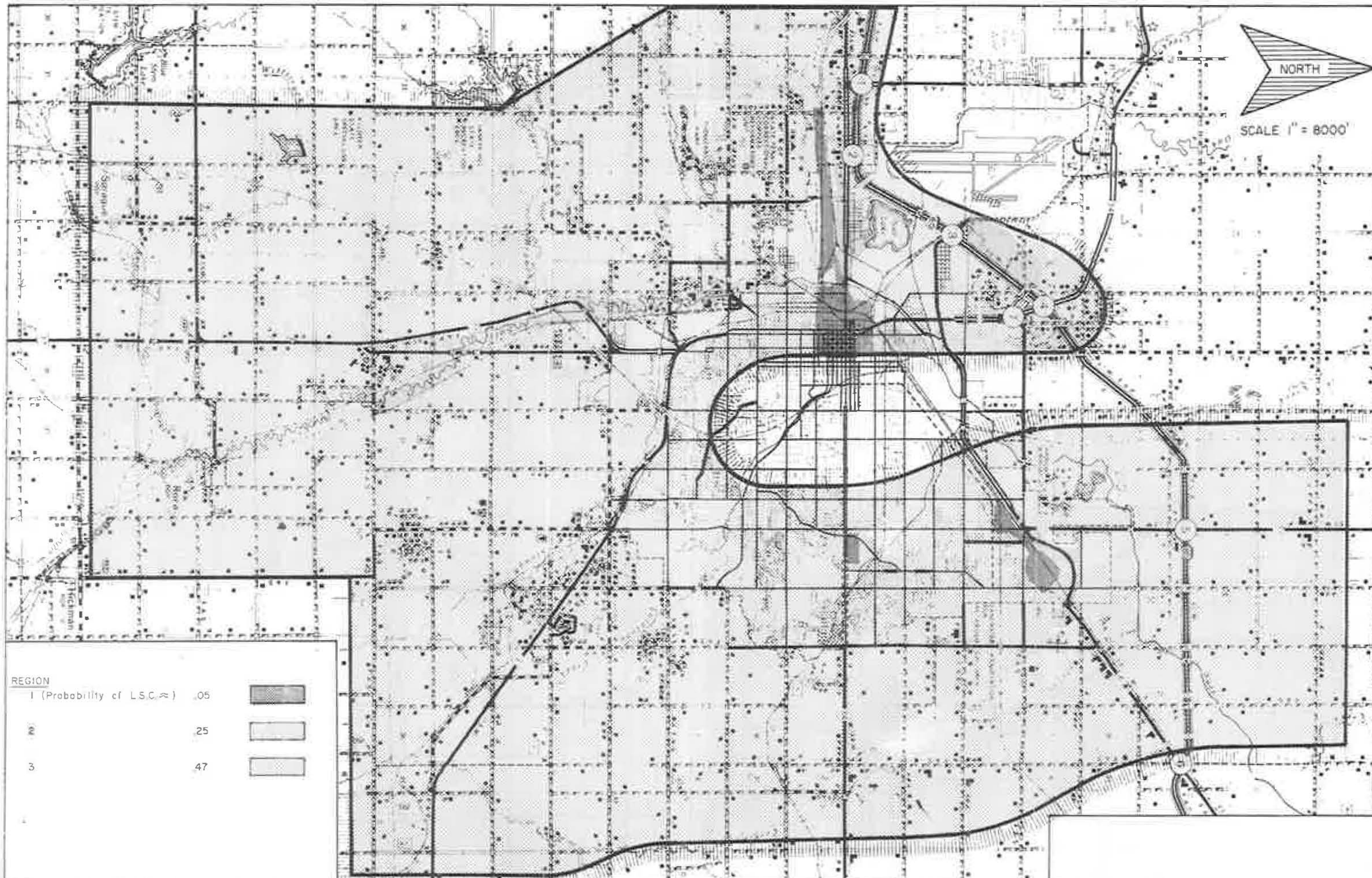

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Figure 9. Cost model.

shown in Figure 6. The corridor selection was made by connecting areas of high probability of least social cost, as shown in Figure 7.

Output from the entire file, that is, from all ten models, was also obtained so that one could determine which point of consideration was paramount in shaping the alignment of the corridor in a specific area. Two of the individual models of interest are noise and facility cost (Figs. 8 and 9).

The modeling technique, as shown in Figure 5, narrowed the alternative corridor locations from nearly an infinite array to a more manageable number. Those corridors remaining after this modeling await an iterative pass through the systems outline (Fig. 1) so that compliance with the study goal and objective can be determined and more specific and detailed study elements and modeling statements can be made before a final corridor is selected.

It is important to note that the time involved in the development of the logic statement, the encoding of knowledge, and the development of the composite model was not extensive, taking only 5 months with a relatively small full-time staff to complete it.

CONCLUSIONS

The results of this study point up several items that are in need of elaboration. Of paramount importance is the ability through this philosophy and methodology to combine elements of seemingly unrelated nature so that they could be operated on and optimized as a net of related intrinsic elements and not a conglomeration of facts and figures.

Also of importance is the fact that the models and the results are quite easily updated, should this become necessary because of an influx of new knowledge. This feature was not the result of a coincidental occurrence. It came about because the entire decision-making process was codified and structured to accommodate this end. The time has passed when it was desirable, if indeed it ever was, to formulate a preconceived result and spend the entire study time in the proof of this biased result.

This methodology also provides a means of optimizing the input from a "design team." Too often in the past a design-team approach to a problem has degenerated into bickering among disciplines or, at best, into honest uncommunicative rhetoric. This philosophy and methodology allow each discipline to make its own input in terms of its own points of concern and then to await the results. In this regard it is a cooperative or normative model and not a collection of compromises.

The universality of this philosophy and methodology carries with it the very real implication that it will have far-reaching impact on the analysis of other problem areas. This is not to say that what has been stated here is sacrosanct and without need of further elaboration; this is not the case. However, one has only to change the goal, objective, study elements, and the E statements to make the technique applicable to planning, architecture, conservation, or any other discipline.

As one approaches any decision-making problem, such as the one of selecting a freeway corridor, a situation cloaked in uncertainty is the only certainty. To have a starting point and to have a direction for proceeding in the midst of this uncertainty, one must have a philosophical procedural outline such as the one stated here. In essence, this outline was used as a schematic descriptive model of the decision-making process.

This descriptive model was also subject to the rules of inductive model building. Hence, no attempt was made to use a transportation systems analysis or a planning systems analysis or an architectural systems analysis. The fact that these procedural formats have been developed for a particular discipline is statement enough about their conformity with the requirement of inductive model building concerning universality.

The system process and model used in this study were an attempt to make the highway location problem more realistic. It was an attempt to use as much information in the pertinent fields as was available with the desire of removing as much uncertainty as possible from the problem at hand. A great many alternatives were evaluated from wide-ranging viewpoints. However, this study is subject to the type of criticism (5) that says, "If the outcome was unsatisfactory, the decision was obviously wrong." This type of criticism seems to define a point of view that states a preposition (5): "Whether a decision was right or wrong is to be decided entirely on the results of the decision and not on the basis of the information available to the decision maker at the time he had to make the decision....But this proposition is an unworkable admonition, because it says in effect, 'always read the future accurately.' Furthermore, it is easy to demonstrate that no one really believes this way." In short, one can only provide a systematic, horizontal, and rational analysis of a problem with its correctness viewed only during that capsule of time and knowledge that was apparent at the point of inquiry and not from the high plateau of hindsight.

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