CHAPTER SEVEN

Strategy for the Energy Crisis: The Case of Commuter Transportation Policy

—Fred S. Roberts

Being able to give advice based on the most accurate possible cognitive map is the task of this chapter. To do this requires getting the consensus of a panel of experts, rather than relying on the causal description that a single person might hold. Therefore, a panel of experts is used in this pilot study of transportation and energy demands first, to get a list of relevant concepts, and then (after narrowing the problem to commuter transportation), to get a consensus of the experts on the causal links between the relevant concept variables.

This chapter is also concerned with what might be called the strategic problem, in contrast to the decision-making problem of Chapter 4 and the explanation problem of Chapter 6. The strategic problem is to determine how the causal links themselves should be changed to give better outcomes. For example, in this empirical study the author finds that the energy demand for intraurban commuter transportation will be stable only if commuter ticket prices go down as ridership goes up. This fascinating result should be regarded as tentative, but it does indicate yet another use of cognitive map analysis, namely, as a way to develop answers to the strategic problem of what changes in the causal relationships in our environment we should try to attain.

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SIGNED DIGRAPHS AND ENERGY DEMAND

In this chapter, I shall be concerned with constructing a cognitive map for use in decision making, rather than with describing a particular person's cognitive map. I shall explore how to build the "best" or most accurate cognitive map possible for use in making decisions. Specifically, I shall concentrate on decision problems involving energy.

The problems of energy supply and demand have recently become more and more important as the seriousness of the "energy crisis" is revealed. In making decisions about energy, one would like to do such things as:

(1) pinpoint the factors underlying the rapidly growing demand for energy;
(2) forecast future demands for energy;
(3) forecast the effect of new technologies or social changes on energy demand and supply;
(4) identify strategies or policies for modifying growth of energy use and meeting various environmental constraints on that use; and
(5) identify alternative strategies for obtaining new energy supplies, and evaluate their potential.

In Roberts (1971), I introduced the idea of studying energy demand by means of a signed digraph, and outlined methods for handling tasks such as (1) through (5). The signed digraph is thought of as an accurate cognitive map to be used in decision making. Additional work on the signed digraph methodology is contained in the works by Brown, Roberts, and Spencer (1972), Roberts (1972a, b, 1973, 1974, forthcoming a, b), and Roberts and Brown (1974). In this chapter, I illustrate the application of signed digraphs to problems of policy making about energy, specifically about energy use in intraurban commuter transportation. I will describe how to construct a signed digraph with which to analyze this area, and illustrate some techniques for analyzing this signed digraph.

One builds a signed digraph for studying energy demand by using as points a collection of variables relevant to energy demand. Then, one draws an arrow from variable x to variable y if a change in x leads to a change in y. As discussed in Chapter 3, one puts a plus sign on the arrow from x to y if a change in x is reflected in y and a minus sign on this arrow if a change in x is reversed in y. (A similar idea is described in Maruyama, 1963.) For illustrative purposes, Figure 7–1 gives a hypothetical example of a signed digraph for energy demand. There is an arrow with a plus sign from population to use, because an increase in population leads to more energy use. There is an arrow with a minus sign from energy use to quality of the environment, because increased use of energy leads to a degradation in environmental quality. I give more details on the construction of signed digraphs after discussing in the next two sections how to analyze them in a policy-making context.

STRUCTURAL ANALYSIS

Once a cognitive map or signed digraph has been built, there are many methodologies for analyzing it. It is useful to divide these into two types, the arithmetic and the geometric.[1] *Arithmetic methodologies* tend to be numerical and precise, and usually aim at the optimization of a few parameters involved in a cognitive map. They tend to be present-oriented and relatively insensitive to change or modification of the basic parameters making up the map. *Geometric methodologies* tend to be rather nonnumerical, and they can take account of variables that are not readily quantifiable. Their aim is an analysis of structure and shape, and especially of changing patterns of structure that may have different ramifications for the future. A typical geometrical conclusion is that some variable will grow exponentially, or that some other variable will oscillate wildly in value. The numerical levels reached are not considered important in such predictions.

Many problems in decision making involve extremely complex cognitive maps with many variables that are not easily quantified, such as environmental quality, freedom, and sovereignty. The use of arithmetical methodologies for studying these problems, though useful and important, will necessarily omit such factors, which at times are of underlying significance. Thus, geometric methodologies must be developed to deal with many important decision-making problems in society. These geometric methodologies should be used in conjunction with arithmetic methodologies.

[1] Cf. Kane (1972), Kane, Vertinsky, and Thompson (1973), and Coady, et al. (1973).

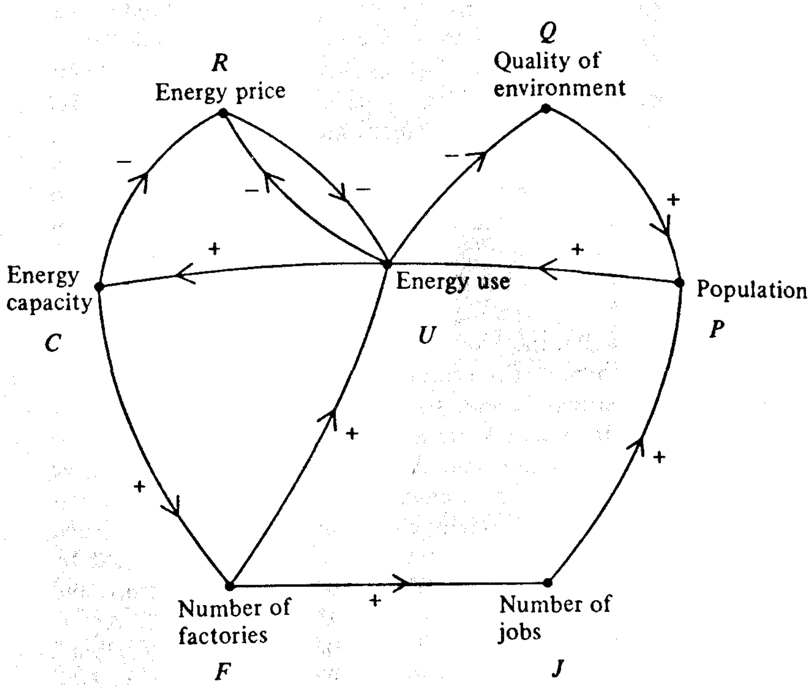
The need for geometric analysis has given rise to a series of new methodologies that are coming to be called, loosely, *structural analysis*. In structural analysis, there are two problems, first the construction of as accurate a cognitive map as possible, and then its geometric analysis, preferably relating geometric conclusions to structural properties of the map. I shall describe both steps of this procedure with regard to problems of energy demand. Similar techniques, with somewhat different approaches to both the construction and the analysis segments of the methodology, are being applied to a wide variety of problems. For example, the Organization for Economic Cooperation and Development (1974) has been applying structural analysis to study the world-wide levelling off of support for scientific research. Coady, et al. (1973) have studied coastal land use, and Antle and Johnson (1973) have studied the effect on inland waterway traffic of large-scale conversion to coal for energy. Health care delivery, transportation, and international sale of water are among the problems studied by Julius Kane and his colleagues (Kane, 1972; Kane, Vertinsky, and Thompson, 1973; Kane, Thompson, and Vertinsky, 1972. Kruzic (1973a, b) has used structural analysis to study deep-water ports and to study naval manpower decisions. Ecologists in the U.S. Forest Service and elsewhere are studying simple ecological food webs, the effect of phorphorus on a lake, the effect of insecticides on cultivated fields, and so on (Levins, 1974, and forthcoming; R. Leary, personal communication).

ANALYSIS OF AN ENERGY DEMAND SIGNED DIGRAPH

Having built an energy demand signed digraph, there are a number of possible uses that can be made of it. Making use of the signed digraph structure, one can identify feedback loops. This is an analysis of *structure*. Feedback loops correspond to cycles in the signed digraph, for example, the cycle in Figure 7–1 that goes from energy capacity to number of factories to energy use, and

FIGURE 7–1.

Signed Digraph for Energy Demand
(Adapted from Roberts, 1971)



back to energy capacity. If energy capacity increases, this leads to an increase in energy use, which in turn leads to further energy capacity. The initial deviation was amplified, and we say there was positive feedback through the system. If there are many positive feedback loops such as this cycle, they will often lead to instability, as small initial changes can be amplified well beyond their initially foreseeable impact. Indeed, in Figure 7–1, every cycle through the energy capacity variable corresponds to a positive feedback loop. This observation makes precise an observation made imprecisely by many environmentalists, and suggests why initial increases in energy capacity lead to more and more such increases. The cycle in Figure 7–1 from energy use to quality of the environment to population to energy use corresponds to a

negative feedback loop. An initial increase in energy use leads to a decrease in environmental quality, which leads people to move out, which in turn leads to a decrease in energy use. The initial deviation was counteracted, and we say there was negative feedback through the system. Negative feedback loops often lead to stability, although they can lead to larger and larger oscillations, also another unstable situation. It is easy to identify negative and positive feedback loops: a cycle corresponds to a positive feedback loop if and only if it has an even number of minus signs, that is, if and only if it is balanced. In sum, identification of positive and negative feedback loops is one step in pinpointing the factors underlying the rapidly growing demand for energy. As has been pointed out in earlier chapters, many decision makers seem to disregard feedback: their cognitive maps have no cycles.

One can also use the signed digraph to identify new strategies for dealing with the energy demand system. Specifically, one can define a *strategy* as any change in the system. A typical change might be to change the sign of one of the arrows. The arrow between energy use and energy price in the signed digraph of Figure 7–1 is a case in point. At present, the more energy you use, the less you pay, which is why the arrow in question has a minus sign. It has been suggested that large users should pay more rather than less—this is the strategy of inverting the rate structure, and it corresponds to changing the sign of this arrow from minus to plus. Now, having seen that a change of sign on an arrow in a signed digraph corresponds to a potential "strategy," one can go about systematically identifying strategies for modifying the energy demand system by looking at all arrows of the energy demand signed digraph. Not all of these are interesting, have real-world interpretations, or are politically or economically feasible, but often we can uncover potentially useful strategies simply by systematically enumerating possibilities.

Many other things can be done with signed digraphs if one imagines that each variable reaches a certain level or value at each time, and these levels change depending on previous changes in other variables. The simplest assumption about how changes of value are propagated through the system amounts to the following. If variable x goes up by μ units at a given time, and there is an arrow from variable x to variable y and a plus sign, then as a result, one time period later variable y will go up by μ units. If variable x goes up by μ units at a given time, and there is an arrow from variable x to variable y with a minus sign, then as a result, one time period later variable y will go down by μ units. These assumptions can be formalized to define a so-called *pulse process.* For the details of this formalization, see Roberts (1971 or forthcoming a, Chapter 4).

If we assume that values change as in a pulse process, then we can consider the effect of new technologies or outside events on the energy demand system. These changes can be thought of as changes in value or level at certain variables, and we can trace out or "forecast" the resulting effect on the system, specifically, the long-term trends in values of other variables. For example, a sudden immigration would correspond to an increase in population level in Figure 7–1, and we would like to forecast the impact on energy use of this increase.

The results from trend forecasting are different from those in the identification of feedback loops. The specific numbers in a trend forecast are not regarded as important. What is important is the geometric nature of the forecast: is it rapid "exponential" growth, is it increasing oscillations, or what? Ideally, a structural analysis will relate the trend forecasts to the structural properties of the signed digraph. These forecasts should be regarded as suggestive, but should be verified by further study and analysis using alternative signed digraphs or other analysis techniques. Let me try to explain why I feel this way. The signed digraph should be regarded as a model of a complex system. As such, it is a simplified model. Conclusions from the signed digraph analysis may thus not be precisely correct, due to the simplifications in the model. What are some of these simplifications? First, signs of effects may change over time, depending on the levels of the variables involved. Second, some effects may be stronger than others. Third, some effects may take longer than others, that is, there are time lags. Fourth, values are assumed to change under the oversimplified rules that make up a pulse process; and so on. Unfortunately, it is virtually impossible, in dealing with complex systems such as the energy demand system, to get precise information as to strength of effects, time lags, and so on. Thus, we must use a simplified model, recognizing only that the conclusions drawn from the model should be subject to further test.

Some of the simplifications mentioned above can be avoided. Information about how effects change over time, if it is available, can be brought into some of the analyses, at least in computer-

generated forecasts of trends. The strength of an effect can be represented by introducing a number (a weight) on each arrow of a signed digraph, obtaining a *weighted digraph.* (This weight represents a strength of effect, not a probability.) Similarly, numbers (or weights) representing time lags can be introduced, giving rise to complicated mathematical problems. See Roberts (forthcoming a) or Roberts and Brown (1974) for a discussion of the analysis of weighted digraphs, and Roberts (forthcoming b) for an example of construction and analysis of weighted and *double-weighted digraphs.* Finally, besides the pulse process rule, other change of value rules can be used. See Kane (1972) for one example. Although any change of value rule will be simplified, if the analysis is done with several alternative rules, and the geometric nature of the conclusions is unchanged, the results should give rise to more confidence.

If we study the trends forecast under various external changes in the system, we might be particularly concerned with the growth of certain variables—energy use, for example. Let us say that a given variable x is *stable* subject to an external change in variable y if the forecast trend in variable x indicates that x does not get larger and larger in value in the situation where an external change is introduced at variable y. This stability might be affected by introducing further external changes, to amplify or counteract the effect of the change in y. But we shall be mostly interested in tracing the unimpeded effect of simple external changes. We shall call the system stable if every variable is stable subject to external changes in any of the other variables.[2] In Brown, Roberts, and Spencer (1972) and Roberts and Brown (1974), techniques are developed for identifying stable signed digraphs. Some of these techniques relate the *geometric* conclusion of stability to the existence of certain *structural* properties of the signed digraphs. These are the theorems of structural analysis.[3]

[2] In my articles, a second notion of stability is discussed. The notion used here is then called value stability.

[3] Briefly, there are two procedures available for determining stability. The first involves calculating the *signed adjacency matrix,* a matrix A whose (i,j) entry is +1 if there is a positive arrow from variable i to variable j, −1 if there is a negative arrow from variable i to variable j, and 0 otherwise. Given the matrix A, one can calculate certain numbers corresponding to A, called the *eigenvalues* of A. An eigenvalue is a complex number a + bi, and its *magnitude* is $\sqrt{a^2 + b^2}$. If every eigenvalue has magnitude less than or equal to 1, if no two nonzero eigenvaleus are the same, and if 1

We shall take it as an important property of a system that it be stable. For us, the prediction of instability will amount to a prediction that the structure of the system will change. It seems that many naturally occurring systems cannot abide with ever-increasing levels at any variable; they eventually undergo a complete change in structure. Prediction of stability is not quite so meaningful as prediction of instability, for a system can stabilize at unacceptably high levels.

Prediction of stability or instability, like prediction of forecast trends in general, should be regarded as suggestive, but again should be verified by further study and analysis. For it, too, is based on the simplifying assumptions inherent in using signed digraphs and pulse processes on signed digraphs.

CONSTRUCTING A SIGNED DIGRAPH

In applying a signed digraph to problems of energy demand, and indeed to many similar problems of society, there are essentially two tasks: the analysis of a signed digraph once it is defined, and the construction of the signed digraph for analysis. Here, I will illustrate how both tasks are handled, by reporting on a specific signed digraph I built and analyzed that had to do with energy demand in transportation.

This signed digraph was built with the help of the subjective judgments of a panel of experts. I am interested in constructing the signed digraph that is based on the best available data, rather than one that best reflects the views of any single person. Therefore, I chose to experiment with the use of subjective judgments of a panel of experts. In many problems of a social or environmental nature, the best available data are the opinions of so-called experts. (Moreover, there is already a considerable literature on expert panels, especially with regard to transportation, using the Delphi method.[4]) For my purpose, the main advantage of using a panel of experts is that it allows me to build a signed digraph that is likely to be more accurate than a cognitive map based on the views of any one person.

is not an eigenvalue, then the signed digraph is stable. The second procedure for determination of stability applies to certain types of signed digraphs (called *advanced rosettes*). For these signed digraphs, it is neecssary to calculate the number a_i given by the number of positive cycles of length i minus the number of negative cycles of length i. If s is the highest number such that $a_s \neq 0$, then stability implies that

(a) $a_s = \pm 1$

(b) $a_i = -a_s(a_{s-i})$ for every $i = 1, 2, \ldots, s-1$

and (c) $a_1 + a_2 + \ldots + a_s \neq 1$.

Each of the conditions (a), (b), and (c) is a structural condition about cycles in the signed digraph. To illustrate this idea, consider the signed digraph of Figure 7–1 (this is an advanced rosette). Here, $a_1 = 0$, $a_2 = +1$, $a_3 = +1$, $a_4 = 0$, and $a_5 = +1$. (Note that $a_3 = +1$ since there are three cycles of length 3, two positive and one negative.) Since $s = 5$, condition (b) is violated for $i = 2$, since $a_2 = 1 \neq -1 = -a_5(a_3)$. We conclude that the signed digraph is unstable. The reader is again warned that these structural results apply only to certain kinds of signed digraphs.

The fact that I have limited my attention to the use of subjective judgments of groups of experts in building an energy demand signed digraph should not be taken to mean that, for all stages of the construction, this is the best available method. Rather, this method should be regarded as one possibility out of several, and the aim of my study was to discover some of its strong and weak points. In the next section, however, I discuss some general guidelines on when the use of expert judgments is appropriate, and how to select groups of experts.

It should be added that it is not reasonable to try to specify one procedure for constructing a signed digraph that provides a cognitive map for decision making. The procedure will vary with the problem being mapped and the use to be made of the map. Even the procedure I do describe has many variations, and each step has choices, possible modifications, and so on. The construction procedure itself teaches the user much about the complex system he is trying to map. Alternative procedures just give more insight into the system. Indeed, trying to build cognitive maps under different sets of assumptions is a useful exercise. The reader should once again distinguish the goal of building a cognitive map to describe a system from the goal of building a cognitive map to describe a particular person's assertions or beliefs.

The problem of building a signed digraph of a system can be divided into three obvious stages: choosing the points or concept variables, choosing the arrows, and choosing the signs.

I look at concept variable definition as a twofold problem. First, one should try to identify as many potentially relevant variables as possible, allowing the imagination to run free. Second, one should attempt to limit the list of variables to a reasonable

[4] Brown, et al. (1969a, 1969b, 1970); Dalkey (1969); Dalkey, et al. (1970); Dalkey and Rourke (1971); Dalkey, et al. (forthcoming).

size by limiting the scope of the problem, by selecting a subset of variables that is most representative or most important. At least for the first problem, the use of subjective judgments of experts seems like the most reasonable procedure, if the term "expert" is used in a very broad sense to include lay people who are knowledgeable or well-read about the problems being considered. For the second problem, it became clear that, if one uses a group of experts, they should, whenever possible, truly be experts in the specific discipline in which they are casting judgment.[5]

A simple way to treat the problems of choosing arrows and signs is to lump them together, and again use expert judgments. The chosen variables are presented as ordered pairs (x, y), and for each such pair each expert judges whether x has a significant effect on y and, if so, what is the sign of this effect. Using expert judgments is, of course, not the only procedure that could be used here, but it is quite a reasonable one if choice of variables is also made by a panel of experts.

To test a potential methodology, I recruited a panel of experts from among the Rand NSF Energy Project team, and sent out three questionnaires. The first two were aimed at choosing the variables of an energy demand signed digraph: the first to identify relevant variables, and the second to limit the list of variables to a reasonable size. I limited the problem initially to energy demand in transportation, and later to energy demand in intraurban commuter transportation. Using the results of the second questionnaire, I sent out a third aimed at determining arrows and signs. The judgments of a number of different experts as to arrows and signs can be combined in various ways to form an energy demand signed digraph, and I chose one such way for illustrative purposes. I analyzed the resulting signed digraph, in particular identifying its feedback loops, determining both its stability and the stability resulting from various strategies corresponding to changing the sign of an arrow.

In what follows, I describe this whole procedure and discuss it critically. It should be emphasized that the main goal at this stage

[5] Methods developed for selecting a set of variables to use in studying energy demand have wider applicability than in choosing points for a signed digraph. Once a set of variables has been systematically selected, it can be used in various other ways—for example, to define scenarios for plausible futures that can be used to study future energy demand patterns. The scenarios could be defined by postulating certain changes in the level of (or relations between) one or more of these variables.

has been to try out a methodology and learn its strengths and weaknesses, rather than to obtain substantive results. However, the procedure, as well as the results, have interesting implications for policymaking.

GUIDELINES ON THE USE OF EXPERT JUDGMENTS

A word is in order about when the use of subjective judgments of experts is an appropriate method. In Dalkey (1969), three kinds of information that commonly play a role in decision making are distinguished. These are called speculation, opinion, and knowledge. To quote Dalkey:

> On the one hand, there are assertions that are highly confirmed—assertions for which there is a great deal of evidence backing them up. This kind of information can be called "knowledge." At the other end of the scale is material that has little or no evidential backing. Such material is usually called "speculation." In between is a broad area of material for which there is some basis for belief but that is not sufficiently confirmed to warrant being called knowledge. There is no good name for this middling area. Here it is called "opinion." The dividing lines between these three are very fuzzy, and the gross trichotomy smears over the large differences that exist within types.

Roughly speaking, the use of subjective judgments of experts has proved useful for dealing with questions falling in the middle area. There is, unfortunately, no really good criterion for deciding to which of the three areas of information a given question belongs. But it is certainly correct to say that choice of the variables for an energy demand signed digraph falls at least in part in the realm of opinion.

The next question that arises is: if we do decide to use expert opinions, which experts do we pick, and should we use a single expert or a group? In general, if a question falls within the realm of a well-defined discipline, such as the design of automobiles, we should use experts from that discipline. Even here, however, experts do tend to disagree on matters of opinion, so it is often wise to use a group of experts. The Delphi studies at the Rand Corporation (Dalkey, 1969) demonstrates that, under controlled interaction procedures with limited feedback of information, the old adage of "two heads are better than one" seems to be upheld in areas of opinion. Although the specific Delphi procedures were not used in the study described here, this and other Delphi results were a justification for using groups of experts, and for letting them make choices without the usual group interaction. Each expert was asked to state his opinion without knowing the opinion of the others.

In the Delphi studies, larger groups have tended to be more accurate and more reliable on matters of opinion.[6] Moreover, the Delphi studies have shown that the controlled interaction leads to more accurate responses than the traditional face-to-face discussion technique of group decision making. A group of experts reaching a judgment in this traditional way has tended to do worse than another group working independently.[7] Groups under controlled interaction have tended to answer even more accurately if the individual judgments are repeated after giving some partial information.[8]

If a question does not fall in the realm of a particular discipline, use of subjective judgments of experts is still quite a reasonable procedure. Here, one should select experts representing all the disciplines that are particularly relevant to the question at hand when forming a group. It is worth noting that recent experiments have demonstrated that a group, each of whose members is expert only in one aspect of a problem, tends to do as well as a group, each of whose members is an expert in all aspects of the problem (Dalkey, et al., forthcoming). In these experiments, members of a group of "synthetic laymen" are each armed with a particular "synthetic fact" relevant to a particular question. Members of a group of "synthetic experts" are each armed with all the synthetic facts. The former group tends to do as well as the latter group, provided the former group, taken as a whole, has all the facts. Thus, it is not necessary that each judge be an expert in every

[6] The questions asked were almanac-type questions, with known answers. These were considered to fall in the realm of opinion for the "experts," because they did not know the exact answer, but had some relevant information with which to make a considered judgment. The group response was taken to be the median of the individual responses. Reliability was measured by taking a correlation between median responses of two randomly selected groups of equal size on a set of twenty questions.

[7] The median of individual responses is usually used as the group's response.

[8] Such as the first round median.

relevant discipline, but only that all relevant disciplines be represented. Finally, a group of experts from different disciplines should, in broad matters such as those of energy use and environment, be supplemented with at least several "lay" experts, knowledgeable or well-read or concerned people who are not necessarily experts in any relevant technical discipline.

ROUND ONE: IDENTIFYING POTENTIAL RELEVANT VARIABLES

I turn now to a description of the identification-of-potential-variables round of the variable choice procedure. To make the later task of limiting variables somewhat simpler, I decided at the very beginning to limit the problem of identification of variables to the transportation sector. This sector was chosen over other sectors of energy use for various reasons, one of which was that a similar study specifically using the Delphi technique and attempting to identify factors relating to quality of life was performed and applied to alternative transportation systems earlier (Dalkey, et al., 1970; Dalkey and Rourke, 1971).

A questionnaire, circulated to the team of experts, asked them to list as many variables as they could think of that might be relevant to (constrain, influence, cause, be affected by, etc.) the growing demand for energy in the transportation sector.

A follow-up questionnaire is, undoubtedly, a very good idea. This would present a summary of first-round responses and a request for additions. I did perform a sort of second round myself, by adding variables suggested by the respondents' variables. In response to the first questionnaire the team of experts succeeded in listing (counting my additions) more than five-hundred variables relevant to energy use in the transportation sector. That seems to me a good indication of the complexity of the energy-use problems with which we are dealing.

There was no hope of organizing this many variables by using techniques of clustering, such as those applied in the quality of life study (Dalkey, et al., 1970). Assuming there were five-hundred variables, this would have called for 125,000 similarity judgments! Instead, I began trying to classify the variables by grouping them. My questionnaire presented examples of relevant variables with the instructions, and these relevant variables were organized into seven categories. Whether because of this means of giving instructions, or because these categories were rather inclusive, almost all the variables listed by the respondents did fit into one of these seven categories. The remainder fitted into one additional category, number 8, below. Next time the questionnaire should be worded so that the examples given are not listed in distinct categories, to avoid the possibility of limiting the responses to these categories.

The eight categories into which all the variables fit are the following:

1. *descriptive variables:* variables describing the transportation system;
2. *design variables:* variables describing the design of the various carriers (car, rail, bus, etc.);
3. *demographic variables:* variables describing life-style, population trends, etc.;
4. *economic variables;*
5. *pollutant variables:* variables describing the different pollutants emitted by transportation modes;
6. *environmental and aesthetic impact variables:* variables describing the impact of transportation on the environment, aesthetics, and the like;
7. *quality-of-life variables;*
8. *energy system variables.*

I found that the variables could also be classified under a rather simple hierarchical classification. This began by characterizing the mode of transportation to which the variable applied: car, rail, bus, truck, plane, water, or pipe.[9] (Some, perhaps less important, modes were also mentioned by respondents: dirigible, motorcycle, hovercraft, bicycle, "feet.") For each mode, the variables relevant to it could be further classified according to the following scheme:

- I. Freight transportation
  - a. short distance (intraregional)
  - b. long distance (interregional)
- II. Passenger transportation
  - a. commuting
    - 1. short distance
    - 2. long distance
  - b. business
    - 1. short distance
    - 2. long distance
  - c. pleasure
    - 1. short distance
    - 2. long distance
  - d. shopping and the like

[9] Some variables apply to all modes.

Not all of the modes had both a freight and a passenger branch, so that this considerably cut down the number of classes. But new variables corresponding to subcategories in this systematic classification were added to the list. In general, such a classification could be sent to experts for comments to see if it suggested additional variables to them.

The first step in limiting the number of variables to be considered was to limit the problem further. I decided to concentrate on just the variables fitting into one subcategory of this classification scheme, and I chose the subcategory of short-distance commuter transportation (for passengers). For simplicity, I chose to deal with only the three most important modes: car, bus, and rail. (The others are not yet as important for intraregional commuter transportation.) Using the eight categories of variables and the three modes given above, I thus was able to organize the remaining variables into twenty-four new subcategories, each corresponding to a given category and mode. Typical subcategories were: descriptive variables—bus; economic variables—car; pollutant variables—car, etc. Table 7–1 shows all the variables in one sample category. Other variables may be found in Roberts (1972a).

It should be remarked that the procedure described so far for organizing variables once they have been defined is not as precise as such techniques as clustering. Much is left to the ingenuity and discretion of the individual analyzing the results. This might be unavoidable, given the large number of variables with which we are dealing. Similar comments apply to the other steps in the procedure for choosing variables. The procedure is defined by a combination of precise rules and ad hoc, subjective ones.

ROUND TWO: LIMITING THE NUMBER OF VARIABLES BY RATING THEIR IMPORTANCE

The technique used to limit further the number of variables was to have the experts rate the importance of these variables. This was done in two ways, for purposes of comparison. Experts were asked for an "overall importance" rating and a "relative importance" rating. The overall importance rating was given on a seven-

TABLE 7–1

QUALITY-OF-LIFE VARIABLES FOR THE RAIL MODE (Category 20)[a]

	Variables	*Median overall importance (1 to 7)*	*Geometric mean relative importance (1 to 100)*
20.1	Comfort of train	4	68.7
20.2	Number of conveniences, lounges, dining rooms, bars, etc.)	3	36.2
20.3	Probability of delay	5	82.3
20.4	Noise level (inside)	4	50.5
20.5	Ride quality	2	28.1
20.6	Degree of concentration required to ride	1	13.2
20.7	Tolerance to high passenger densities	4	58.3
20.8	Crowding (number of passengers per square foot)	4	68.9
20.9	Number of passengers per train	3	42.7
20.10	Number of seats abreast	3	59.3
20.11	Aesthetic impression of travel route	3	27.0
20.12	Convenience of schedule (frequency)	6	85.6
20.13	Number of trains daily	5	80.4

[a] Kendall's τ for this subcategory is 0.83, which is significant at 0.001.

point scale, with 1 meaning "unimportant," 4 meaning "moderately important," and 7 mean "extremely important." The relative importance of a variable was obtained on a scale of 1 to 100, using the magnitude estimation procedure. Experts were asked to rate the given variable relative to other variables in the same subcategory. The most important variable in the subcategory was chosen and given a rating of 100. The other variables were rated in terms of the most important one, so that a variable receiving a rating of 50 was considered "half as important" as one receiving a rating of 100, and so on. Use of the two specific rating schemes chosen was modeled after the procedure used in obtaining importance ratings in Dalkey and Rourke (1917).

In all, seven respondents returned their completed questionnaires for Round 2. I computed the median overall importance rating over responses for each variable, and the geometric mean of

relative importance ratings over responses for each variable. These statistics are shown for a sample subcategory in Table 7–1. (The reader is referred to Roberts, 1973, for a discussion of why I chose these statistics.)

I also computed Kendall's τ, a coefficient of rank correlation, between median overall ratings and geometric mean relative ratings for each subcategory. As expected, there was a great deal of agreement between the two ranking procedures. (See Roberts, 1972a, for detailed data.)

The ratings raised some rather interesting points. No environmental or aesthetic variable received even a "moderately important" rating in the rail and bus subcategories, and only the variables "accidents" and "land use impact" received ratings as high as 5 among all the environmental and aesthetic variables. Was this because it was the consensus of the experts that environmental and aesthetic variables are not as important for the study of energy demand as are some of the other variables? Or was it because the first round did not produce environmental variables that are considered important?

For the economic variables, the consensus of the experts was that the cost of reducing emissions to acceptable levels was relatively unimportant. Among the variables related to cost of emission reduction, the highest median overall importance rating was 3. But one expert did add a note on his questionnaire, saying that he would rate them higher if the variables were stated as "cost of reducing . . . emissions (if this cost $>$ x percent of the cost of the car)," and x was large enough.

There were several important issues raised by the ratings in the three subcategories dealing with pollutant variables. The method of measuring emissions that received the highest importance rating was, in general, "emissions per passenger mile," rather than "total emissions," "average emissions per day," or "total emissions on maximum day." Some participants, however, felt that there was no a priori way to decide which means of measurement is better or leads to a "more important" variable. In general, carbon dioxide emissions, particulate emissions, and noise emissions received lowest median overall importance ratings, while carbon monoxide, nitrogen oxide, and hydrocarbon emissions received highest ratings. Some respondents felt that they were not well enough informed to make intelligent ratings of importance in these subcategories. These were singled out, more than any others, as ones where ratings would best be done by experts in the particular subcategory.

CHOICE OF VARIABLES

There are a number of alternative procedures for choosing variables as points for a signed digraph, given results such as those from Round 2. It is probably best first to choose a preliminary list of variables, and then further to limit the list. For each of these steps, there are again a number of alternative methods. It is probably not a good idea to try to limit oneself to one method for choosing variables as best in all circumstances. Rather, different methods might be more appropriate for different sets of data. When several methods seem appropriate, it might be worthwhile to build several lists of chosen variables, using different methods. These lists can be used to build several signed digraphs, each of which could be useful. (Again, just the process of construction and analysis of several signed digraphs can help the experts understand the complete processes they are modeling.) If there is a good reason for wanting one final signed digraph, the choice among the final signed digraphs can be left to the experts.[10]

For choosing the preliminary list of variables, the following methods suggest themselves: [11]

Method 1. Choose one or two variables from each subcategory on the basis of overall or relative importance.

Method 2. Choose one or two variables from each subcategory

[10] If a more systematic procedure for choosing a consensus among alternative signed digraphs is desired, a promising technique is that used for choosing a consensus among alternative partial orders in Bogart (1971). It has been pointed out by Bogart (personal communication) that the procedure generalizes in a straightforward way to the case of signed digraphs.

[11] There are a number of variants of these methods, using more sophisticated statistical techniques. The problem of choosing one variable (or one ranking) out of a subcategory, when presented with differing rankings by a group of experts, has been studied in some detail in the literature. Statistical procedures are described in Kendall (1962) and Friedman (1937). One particularly interesting procedure, somewhat different and not well known, is that used by Kemeny and Snell (1973, chapter 2). They describe how to calculate the distance between two rankings, and then pick a consensus ranking as one centrally located among the alternative rankings, as far as the distance measure is concerned. (Bogart's procedure, referred to in the previous footnote, is a generalization of this one.)

that has at least one variable with overall importance rating of, say, 6 or more. The problem here is that not every major category will necessarily be represented.

Method 3. Choose all variables, regardless of subcategory, that have overall importance ratings of, say, 6 or more. Again, not every major category will necessarily be represented.

Method 4. Choose one or two variables from each collection of subcategories belonging to a given category.

After a preliminary list of variables has been chosen, it can be further limited by applying one of several methods, possibly with a number of iterations. Some possible methods are:

Method A. Obtain relative importance ratings among the variables on the preliminary list, and choose the most important ones.

Method B. Use a clustering procedure.

Method C. Choose only those variables on the preliminary list that have overall importance ratings of, say, 5 or greater.

For illustrative purposes, I decided to use Method 1 on the data, with the choice based on the median overall ranking, and a geometric mean relative ranking used in case of ties. Then I limited the list with Method B, and refined the list further with Method C.

By using Method 1, a preliminary list of twenty-four variables was chosen. These preliminary variables clustered into well-defined groups; that is, variables in subcategories of the same category tended to be closely related, and could usually be lumped together. Without performing a sophisticated clustering analysis, as in Dalkey, et al. (1970), I chose ten variables to replace the initial twenty-four. These variables were different from those in the initial subcategories—they were, of course, the lumped variables. For example, one lumped variable was "probability of delay," which was obtained by lumping probability of delay (car), probability of delay (bus), and convenience of schedule (rail). In general, it might be necessary to perform a more sophisticated clustering analysis, though the present clustering was deemed satisfactory for illustrative purposes. A second iteration to limit the list of variables further was performed using Method C. Here, one variable was eliminated, since its overall importance rating was only 3. This left nine variables in all, the ones shown in Table 7–2.

TABLE 7–2

VARIABLES CHOSEN IN ROUNDS 1 AND 2

	Variable	Abbreviation	Category
1	Number of passenger miles (annually, over all commuter modes)	Passenger miles	Descriptive
2	Fuel economy (miles per BTU, average over all commuter modes)	Fuel economy	Design
3	Population size	Population size	Demographic
4	Cost of car	Cost of car	Economic
5	Price of commuter ticket (average over all modes)	Price of commuter ticket	Economic
6	Tons of emissions per passenger mile (averaged over all modes, and including carbon monoxide, nitrogen oxides, and hydrocarbons, but not carbon dioxide, particulates, or noise)	Emissions	Pollutant
7	Accidents	Accidents	Environmental and aesthetic impact
8	Probability of delay	Probability of delay	Quality of life
9	Total fuel consumption (over all modes)	Fuel consumption	Energy system

CHOICE OF ARROWS AND SIGNS: THE ROUND THREE PROCEDURE

With the nine variables chosen as a result of Round 2 (see Table 7–2), a questionnaire was prepared and sent asking the panel of experts to indicate for each ordered pair of distinct variables (x,y) whether, all other things being equal, a change in variable x has a significant effect on variable y, and if so, whether the change in x is reflected or reversed in y. This led to assignment of a sign + or −, or assignment of a 0 (corresponding to a negligible effect), to each ordered pair (x,y), with $x \neq y$. (With his instructions each expert was given a pack of seventy-two cards, one for each ordered pair of variables (x,y) with $x \neq y$. The cards were shuffled before being distributed to attempt to minimize the effect of extraneous order-of-presentation factors. Each respondent received a deck in a different order. Perhaps in the future a more sophisticated randomization technique than mere shuffling of cards could be used, but here, as in Rounds 1 and 2, the outlines of the methodology were considered more important than the details.)[12]

The procedure described is sometimes called *cross-impact analysis*. Asking for interaction data in a systematic way for each ordered pair of variables seems to avoid many problems. Cognitive maps described in this book often have few or no feedback loops, and otherwise omit important effects. The simple act of systematically considering all pairwise impact should significantly diminish the possibility that important effects and feedback loops will be omitted. The reader will notice later that there are a fair number of feedback loops in the signed digraph presented below.

Choice of arrows and signs, just as choice of variables, can be very "context-sensitive." It has been pointed out to me by J. Baird (personal communication) that it might be reasonable to spell out for the experts the context in which they are making their judgments before gathering their responses. Thus, they might be given a scenario describing various social, technological, or economic changes that have been made from the present, and be asked to make their judgments relative to such a scenario. Different signed digraphs would be built under each scenario. Exactly this procedure is carried out in Roberts (forthcoming b), where the impact of energy use on clean air in San Diego transportation is studied in two different scenarios, one a "business as usual" nominal case, in which transportation is almost completely by private automobile, and the other a radical all-bus case, in which automobiles are banned from San Diego and a wide-ranging bus system is introduced. Once again, the reason we can consider alternative signed digraphs rather than one cognitive map is that we are not trying to describe an individual's cognitive map. Rather, we are trying to build a map as an aid in decision making. In different contexts, different maps are called for.

To give an example of how sensitive judgments of sign can be to the scenario, suppose we consider in intraurban commuter transportation the sign of the arrow from the probability of delay to emissions. The sign of this arrow will depend upon the pattern

[12] It should be remarked that it is relatively straightforward to extend the methodology to obtain numbers (weights) representing the relative strength of the effect of a change in x or y, and the time lag before the effect takes place. See Roberts (forthcoming b).

of commuting in the area. If a high fraction of commuting is accomplished by automobile (as in Los Angeles, for example), then the increased stop-and-go driving caused by delay will increase the amount of pollutants. If, on the other hand, a large fraction of commuting is by electric subway or train (as in New York, for example), then delays will not have great influence on pollutants (since no power is being used in "idling"), and might even somewhat decrease the effluents from electric power stations.[13]

BUILDING THE SIGNED DIGRAPH

There were seven respondents in Round 3. The data from these respondents are summarized in Table 7–3. One respondent put

TABLE 7–3

ROUND 3 DATA

Variable pair x,y	Respondents 1	2	3	4	5	6	7	Totals[a] 0	+	−	?
1,2	+	0	0	0	0	+	+	4	3	0	
1,3	0	0	0	0	0	0	0	7	0	0	
1,4	0	0	−	0	+	−	0	4	1	2	
1,5	−	−	+	−	+	+	−	0	3	4	
1,6	+	+	0	+	+	+	0	2	5	0	
1,7	+	+	+	+	+	+	+	0	7	0	
1,8	0	+	+	+	+	+	+	1	6	0	
1,9	+	+	+	+	+	0	+	1	6	0	
2,1	−	0	0	+	+	0	+	3	3	1	
2,3	0	0	0	0	0	0	0	7	0	0	
2,4	−	(−)	−	0	0	−	0	4	0	3	
2,5	−	−	0	−	−	−	−	1	0	6	
2,6	−	−	−	−	−	−	−	0	0	7	
2,7	0	0	0	0	−	+	0	5	1	1	
2,8	0	0	0	0	0	−	0	6	0	1	
2,9	−	−	−	−	−	+	−	0	1	6	
3,1	+	+	+	+	+	+	+	0	7	0	
3,2	0	0	0	0	0	0	0	7	0	0	
3,4	0	−	0	−	0	0	0	5	0	2	
3,5	0	(−)	0	−	+	0	0	5	1	1	
3,6	+	+	+	+	0	+	+	1	6	0	
3,7	+	+	0	+	+	+	0	2	5	0	
3,8	+	+	+	+	+	+	+	0	7	0	
3,9	+	+	+	+	+	+	+	0	7	0	
4,1	0	0	0	0	−	0	0	6	0	1	
4,2	−	(+)	0	0	−	−	+	3	1	3	
4,3	0	0	0	0	0	0	0	7	0	0	
4,5	+	−	0	−	+	+	0	2	3	2	
4,6	+	−	0	0	0	−	0	4	1	2	
4,7	−	(−)	0	0	0	−	−	4	0	3	
4,8	0	0	0	0	0	0	0	7	0	0	
4,9	+	+	0	0	+	−	0	3	3	1	
5,1	+	−	−	−	−	−	−	0	1	6	
5,2	0	+	−	0	0	0	0	5	1	1	
5,3	0	0	0	0	0	0	0	7	0	0	
5,4	+	0	0	−	+	+	0	3	3	1	
5,6	0	−	0	+	0	+	+	3	3	1	
5,7	0	−	0	+	0	+	0	4	2	1	
5,8	0	−	0	+	0	−	−	3	1	3	
5,9	0	0	0	+	−	+	+	3	3	1	
6,1	+	0	0	0	−	−	−	3	1	3	
6,2	−	+	0	0	+	−	−	2	2	3	
6,3	0	0	0	0	−	−	−	4	0	3	
6,4	−	+	0	0	−	−	0	3	1	3	
6,5	0	−	0	0	0	+	0	5	1	1	
6,7	+	+	+	0	0	+	+	2	5	0	
6,8	0	0	0	0	0	+	0	6	1	0	
6,9	+	−	0	0	+	−	−	2	2	3	
7,1	0	0	0	−	+	−	−	3	1	3	
7,2	0	(−)	0	−	0	0	0	6	0	1	
7,3	−	(−)	0	−	0	−	−	3	0	4	
7,4	0	+	0	−	0	0	0	5	1	1	
7,5	0	+	?	0	0	+	0	4	2	0	1
7,6	0	(+)	0	+	0	−	0	5	1	1	
7,8	+	+	+	+	+	+	+	0	7	0	
7,9	0	0	0	+	0	0	0	6	1	0	
8,1	0	−	−	−	−	−	−	1	0	6	
8,2	0	−	0	0	−	−	−	3	0	4	
8,3	−	0	0	?	0	0	0	5	0	1	1
8,4	0	0	0	0	+	0	0	6	1	0	
8,5	0	+	0	0	?	+	0	4	2	0	1
8,6	0	+	+	0	+	+	+	2	5	0	
8,7	−	0	0	0	+	+	−	3	2	2	
8,9	−	+	+	0	0	−	+	2	3	2	
9,1	−	−	−	−	0	−	0	2	0	5	
9,3	0	0	0	0	0	0	0	7	0	0	
9,4	+	0	0	0	0	+	0	5	2	0	
9,5	+	+	0	−	0	−	0	3	2	2	
9,6	+	+	+	+	+	−	+	0	6	1.	
9,7	+	0	0	0	0	0	0	6	1	0	
9,8	0	0	0	0	+	−	0	5	1	1	

[a] Counting (+) and (−) as 0. (+) and (−) mean "weakly."

[13] The author thanks J. Bigelow and J. DeHaven for making this observation.

some of his plus and minus responses in parentheses, indicating this meant "weakly." In the analysis these "weak" effects were counted as no effects, though a similar analysis could be used if they were counted as strong effects. There were three cases of missing data. For purposes of the analysis below, these three cases turned out to be unimportant, since they were all cases in which a majority of the respondents listed the effect as negligible.

There are a number of plausible techniques for combining the data of Table 7–3 to form a signed digraph, though there does not seem, *a priori,* to be a good way to distinguish among these various procedures. Indeed, digraphs built under different procedures could again be usefully compared and contrasted. Perhaps it clarifies the selection procedure if construction is based on two separate decisions:

(1) Is there an arrow (x,y)?

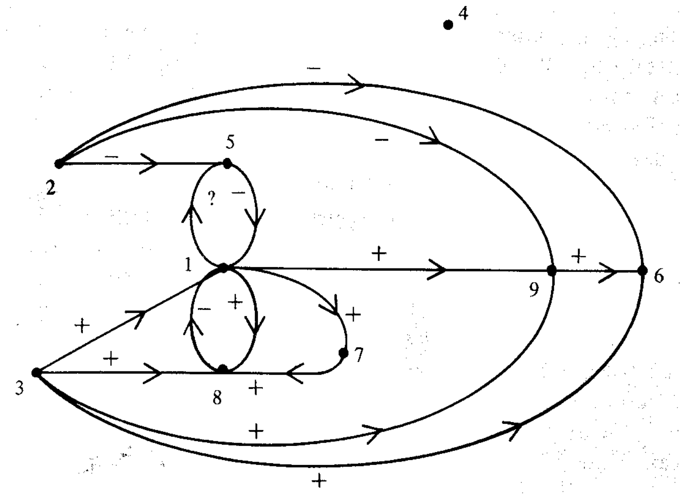
(2) If so, what is the sign of this arrow?

If we use this two-step decision procedure, the following method seems reasonable. If at least six of the seven respondents said there was a significant effect on y if there is a change in x, then include (x,y) as an arrow. Moreover, give (x,y) that sign agreed to by 60 percent of the respondents, if there is this much agreement. If this procedure is used on the data of Table 7–3, there is only one undecided sign, that on the arrow from passenger miles (variable 1) to price of commuter ticket (variable 5). Here all seven experts felt there is a significant effect, but three felt the effect is plus, while four felt it is minus. We can summarize the data in the signed digraph G of Figure 7–2, putting a question mark (?) on the arrow (1,5). In our analysis below, we consider the various possible choices of sign on this arrow (including sign 0, which is interpreted as not having the arrow).

There are, of course, other plausible procedures for building a signed digraph from the data of Table 7–3. We could vary the number of experts who have to agree on the existence of a significant effect. We could vary the number of experts who have to agree on a sign before we definitely choose that sign. A quite different procedure would be the following: if any two experts who say there is an arrow disagree on the sign of the arrow, then let there be no arrow. If all who say there is an arrow agree on the sign, then let there be an arrow only if there is a large enough number of experts who think there is one, and if so, give the arrow the sign chosen by all experts believing in arrows. Still a different

FIGURE 7–2.

Signed Digraph G Constructed from Expert Data of Table 7–3



Key to Figure 7–2

1	Passenger miles	6	Emissions
2	Fuel economy	7	Accidents
3	Population size	8	Probability of delay
4	Cost of car	9	Fuel consumption
5	Price of commuter ticket		

procedure is the following: let x be the number of experts who say there is a positive arrow minus the number of experts who say there is a negative arrow. If x is sufficiently large and positive, introduce an arrow and make it positive. If x is sufficiently large and negative, introduce an arrow and make it negative. As we mentioned before, there seems to be no a priori reason for choosing one of these alternative procedures (or other equally plausible ones) over another.

ANALYZING THE SIGNED DIGRAPH

Having constructed a signed digraph such as G by the method described in the previous section, we can apply the methodology developed in Brown, Roberts, and Spencer (1972) and Roberts and Brown (1974) to analyze the signed digraph. In particular, we shall illustrate this application by discussing the stability of the energy demand system described by the signed digraph G (Figure 7–2). We shall also consider the effect of various strategies for modifying the energy demand system, and see which of these is stabilizing. We shall do the same with various outside events, determining which of these lead to stability and which to instability. Throughout, we shall consider the policy implications of the conclusions.

A detailed analysis of the stability properties of the signed digraph G may be found in Appendix B of Roberts (1972b), though the more up-to-date techniques of Roberts and Brown (1974) can be used to make an even simpler analysis. To summarize the results, we recall that the system is called *stable* if the value of no variable gets larger and larger in any situation in which some external change is introduced at some other variable. The stability of signed digraph G will depend, of course, on the sign of the arrow (1,5) from passenger miles to price of commuter ticket. Line 1 of Tables 7–4, 7–5, and 7–6, respectively, shows

TABLE 7–4

EFFECT OF VARIOUS STRATEGIES ON SIGNED DIGRAPH G WITH ARROW (1,5) TAKEN AS +

Strategy: change sign of edge	*Evaluation*	*Stable starting variables (in new signed digraph)*	*Unstable starting variables*
none	unstable	[4, 6, 9]	[1, 2, 3, 5, 7, 8]
18, 51	stable	all	none
all others	unstable	[4, 6, 9]	[1, 2, 3, 5, 7, 8]

TABLE 7–5

EFFECT OF VARIOUS STRATEGIES ON SIGNED DIGRAPH G WITH ARROW (1,5) TAKEN AS –

Strategy: change sign of edge	*Evaluation*	*Stable starting variables (in new signed digraph)*	*Unstable starting variables*
none	stable	all	none
17, 78	unstable	[3, 4, 6, 9]	[1, 2, 5, 7, 8]
18, 51, 81	unstable	[4, 6, 9]	[1, 2, 3, 5, 7, 8]
all others	stable	all	none

TABLE 7–6

EFFECT OF VARIOUS STRATEGIES ON SIGNED DIGRAPH G WITH ARROW (1,5) TAKEN AS 0

Strategy: change sign of edge	*Evaluation*	*Stable starting variables (in new signed digraph)*	*Unstable starting variables*
none	unstable	[4, 6, 9]	[1, 2, 3, 5, 7, 8]
all others	unstable	[4, 6, 9]	[1, 2, 3, 5, 7, 8]

stability in each of the three cases: the signed digraph is stable if arrow (1,5) is minus, and not stable otherwise. We shall discuss the significance of this conclusion in the next section.

The first lines of Table 7–4, 7–5, and 7–6 also give us some information about the effect of certain outside events on the energy demand system, those outside events that correspond to a change in some variable x. We shall call variable x a *stable starting variable* if, whenever a sudden increase is introduced at variable x, the resulting changes in the system lead to stability at each other variable. That is, x is a stable starting variable if a sudden increase in x does not lead to ever-larger values somewhere in the system. Thus, we see from Table 7–4 that if the arrow (1,5) is plus, the variables cost of car (4), emissions (6), and fuel consumption (9) are stable starting variables, and the rest of the variables are not. That is to say, a sudden increase in fuel consumption will not lead to indefinite growth in other variables in the system, while a sudden increase in price of a commuter ticket (5) will. We shall discuss the meaning of these predictions in detail below. In the same way, we note from line 1 of Table 7–5 that if the arrow (1,5) is taken to be minus, then every variable is a stable starting variable. The system is so stable that sudden external changes imposed at any of its variables do not lead to arbitrarily large values anywhere.

One important remark must be made about stable starting variables. The reader will recall that we analyze stability given an initial increase in a variable x under the assumption that further external influences are not introduced into the system. The instability comes from the propagation of changes *within* the system itself. Thus, if a given variable is known to be an unstable starting variable, the unstabilizing tendencies could be counteracted by introducing further external changes in the system at other variables.

Table 7–7 gives more detailed descriptions of stability properties of the signed digraph G. Specifically, we see that fuel consumption (9) will grow unboundedly large in the situation where arrow (1,5) is plus and an external increase is introduced at one of the

TABLE 7–7

STABILITY OF VARIABLES IN G UNDER STRATEGIES GIVEN IN TABLES 7–4, 7–5, and 7–6

Variable	*Stability behavior*
1, 6, 7, 8, 9	Unbounded in value from external changes at any of the unstable starting variables
2, 3, 4	Bounded regardless of starting variables
5	Unbounded from external changes at unstable starting variable if and only if arrow (1, 5) exists

unstable starting variables, such as price of commuter ticket (5). However, population size (3) will remain bounded in value regardless of the sign of arrow (1,5), and regardless of where an external change is introduced. (We shall discuss this prediction below.) Once again, these predictions are made under the assumption that no external changes outside of an initial one are introduced.

One of the advantages of the signed digraph technique is that it allows us to evaluate the effect of various strategies, that is, deliberate changes in the energy demand system. Specifically, we are interested in strategies that correspond to changing the sign of a given arrow, and in discovering which of these strategies lead to stability. Tables 7–4, 7–5, and 7–6 show the stability of any signed digraph resulting from changing the sign of any given arrow in signed digraph G. Also indicated are the stable and unstable starting variables corresponding to each new signed digraph. We see, for example, from line 2 of Table 7–4 that if the arrow (1,5) is plus, and we change the sign of arrow (1,8), this strategy is stabilizing. However, if we change the sign of arrow (2,5) this strategy is not stabilizing. Again, we shall interpret the results in the next section. It is easy to discover what strategies will be stabilizing by studying the structural properties of the digraph.

Those strategies that make a certain cycle positive turn out to be the stabilizing ones. We shall see this below.

CONCLUSIONS AND DISCUSSION

In this section, we shall try to translate the graph-theoretical conclusions of the previous section into statements about the demand for energy, about policies for changing demand, and so on. We shall assume that the signed digraph G is an accurate model of the energy demand system, and the pulse process assumption of propagation of values is accurate enough. Then we shall discuss the various predictions attainable from the signed digraph. It should be understood that many of these predictions, especially those on stability, are to be regarded as tentative and suggestive, and should be tested by other means.

Specifically, we shall deal with the following issues, taking them as illustrative of the kinds of analyses possible with a signed digraph. First, should the price of commuter tickets be set as a function of passenger miles, and if so, should the price go up when passenger miles go up, or should it go down? Second, what strategies for changing the energy demand system in transportation are stabilizing? Third, of the various strategies considered, which are really feasible, that is, which can be implemented in practice? Finally, what feedback loops contribute to the instability of the situation?

Stability

Studying the results in Tables 7–4, 7–5, and 7–6, we note first that if the arrow (1,5) is 0, that is, if a change in number of passenger miles has an insignificant effect on the price of a commuter ticket, then the situation is unstable, and no strategy from the simple ones we have considered can change the situation. If the arrow (1,5) is plus, the situation is also unstable. Changing the sign of the arrows (5,1) or (1,8) makes it stable. If arrow (1,5) is minus, the situation is stable. Any strategy changing the sign of an arrow joining any pair of variables among 1, 5, 7, and 8 will destabilize the situation.

These conclusions can be interpreted as follows. It is suggested that if prices of commuter tickets are set as a function of total passenger miles, with prices decreasing as total passenger miles increase, then the energy demand system (in intraurban commuter transportation) will be stable. That is to say, under any external change in any of the relevant variables, no other variable will grow arbitrarily large. (This is not predicted if continuing changes are introduced at any variable.) If the pricing of commuter tickets is not critically dependent on passenger miles, or if the price is increased when passenger miles increase, then the situation will be unstable. That is to say, external changes in certain variables can lead to arbitrarily large values at other variables. For example, as we shall see below, it is predicted that emissions and fuel consumption will grow arbitrarily large if population is given an external increase. In the case in which the price of a commuter ticket increases when passenger miles increase, there are possible stabilizing strategies of a simple nature: arranging that passenger miles decrease as price of commuter tickets increases, or arranging that the probability of delay goes down as passenger miles increase. The question of whether these strategies are feasible, that is, whether they can be implemented, becomes a crucial one. We return to it below. If we think stability is important to attain, and instability is to be avoided, even using the limited notion of stability we are dealing with, the policy implications are quite clear. However, even if stability is attained, it is important to emphasize again that things might stabilize at unacceptably high levels, so further "forecasts" of future levels should probably be made.

The results on stability are conveniently stated by cases that are defined in terms of the sign of the arrow (1,5). This should not be taken to mean that arrow (1,5) is more important than any of the other arrows. It was, however, an arrow about which there was considerable disagreement. Analysis of why there was disagreement can be very useful. In this case, it might be due to the extreme sensitivity of the effect to context. That is, under certain scenarios, it might be reasonable to assume that an increase in passenger miles has no effect on the price of commuter tickets. This might be true if it has been decided as a matter of policy to make commuter tickets free. On the other hand, under other scenarios, it might be reasonable to charge more per commuter ticket if passenger miles went up. This might be the case if there were a very limited capacity, and it was hoped that the number of passenger miles could be limited.

Tables 7–4, 7–5, and 7–6 also list stable and unstable starting variables under the various sign change strategies. This allows us

to evaluate the effect of introducing changes in certain variables under these sign change strategies. For example, we see that if arrow (1,5) is minus, then the introduction of a sudden increase in population size (3) leads to instabilities only if one of the arrows (1,8), (5,1), or (8,1) is changed in sign. Similarly, if arrow (1,5) is plus, then any increase in price of commuter tickets (5) leads to instability.

We have already observed that Table 7–7 gives more detailed information on the stability behavior at various variables. For example, expanding on the instabilities brought on by an increase in commuter ticket prices (5) if arrow (1,5) is plus, we see that this leads to large values in such important variables as tons of emissions (6) and fuel consumption (9). Another potentially interesting conclusion from Table 7–7 is that population size (3) is bounded regardless of starting variable. Such a conclusion can be interpreted in a number of ways. It is not necessarily surprising, in the sense that population can become rather large without being unbounded; all the conclusion asserts is that the population size variable has a bound beyond which it does not grow. Further, the conclusion does not assert that population will remain bounded if repeated outside changes are introduced. But it does imply that population will remain bounded by the operation of feedback in the system so long as no repeated external changes are made. The analysis predicts that this will not be the case for such other variables as emissions or fuel consumption. Thus, the prediction is that these variables will grow large much faster than population; or alternatively, that the structure of the system will change before that happens.

Strategies

One of the useful applications of the signed digraph technique is in the systematic generation of potentially useful strategies, which then can be evaluated by other methods. These strategies can be generated without introducing precise models of the kind that would be needed to be sure of the conclusions about stability.

The signed digraph G generated by the experts gives rise to a large number of strategies relevant to energy demand in the intra-urban commuter transportation sector. In particular, all strategies corresponding to changing the sign of an arrow are of potential interest. The analysis we have made, that is, one based on stability, suggests that the most promising strategies to consider further correspond to changing arrow (1,5) to minus, or, if (1,5) is determined to be plus, then to changing arrow (5,1) or (1,8). Relatively little attention has heretofore been given to these particular strategies in the way they relate to energy demand, in particular to the strategy of changing the sign of the arrow (1,8). (We shall further discuss this strategy below.) In addition to these strategies, the analysis has defined many other strategies that might be worth assessing, using other techniques. Thus, although the signed digraph analysis has indicated that change of the sign of arrow (2,5) (to choose an arrow from G at random) will not change stability, at least it has identified this as a potential strategy that perhaps should be evaluated by other methods. Perhaps analyzing this effect, that of change in fuel economy on price of a commuter ticket, will be interesting.

It is one thing to try to analyze strategies once they are given, and another thing to try to pinpoint ahead of time which strategies are likely to be effective. The structure of the signed digraph can be used to pinpoint such strategies. Indeed, the conclusion that if (1,5) is plus, then changing the sign of arrow (5,1) or arrow (1,8) is stabilizing, was first suggested by structural analysis of the cycles of the signed digraph.

It should be remarked that there are other strategies than changing the sign of an arrow. Some involve changing the sign of several arrows. For example, we might want to try to change the sign of both arrows (5,1) and (1,8) at the same time, thus changing the effect of an increase in price of commuter ticket on passenger miles *and* the effect of an increase in passenger miles on the probability of delay. (Incidentally, a stability analysis indicates that if (1,5) is plus, then making both these changes simultaneously leaves the unstable situation that prevailed before the simultaneous changes.) Another type of strategy could eliminate or add arrows. For example, variable 4 (cost of car) is now isolated, and it might be considered important to give this variable a role by introducing an arrow with a minus sign from it to passenger miles. Conversely, if (1,5) is 0, that is, if the price of a commuter ticket does not depend on passenger miles, then a stabilizing strategy is to eliminate the arrow (1,8), that is, to eliminate the effect of passenger miles on probability of delay. Similarly, a strategy might correspond to the addition of new variables. One such variable might be public expenditure on pollution control. This variable might have a negative arrow leading to emissions, and a positive arrow leading from emissions. Finally, one could define various strategies that correspond to inducing certain external changes in various variables, independent of the operation of the system itself. A typical strategy might be to add 10 percent to the cost-of-car variable every time period, say every two years. We have analyzed only the strategies that correspond to changing the sign of a single arrow. These other strategies can and should be analyzed similarly. But the kinds of conclusions attainable are in principle quite similar, namely, whether a given strategy is stabilizing, what future trends will follow from different strategies, which variables are stable under different strategies, which variables will reach unboundedly large values, and so on.

Feasibility [14]

Let us consider briefly the feasibility of the strategies corresponding to changing the signs of the arrow (1,5), (5,1), and (1,8). Questions of feasibility are, of course, not signed digraph questions. We are asking whether these strategies could be implemented, and if so, how.

It might be feasible to change the sign of the effect of an increase in the price of a commuter ticket on passenger miles, the sign of arrow (5,1). This could be through a system of "time-pricing," as discussed in Vickrey (1968). The idea is that ticket prices do not remain uniform, but are raised during peak demand periods (to reflect their contribution to fixed costs), and are lowered during off hours to attract riders. By using this procedure carefully to set ticket prices, it is possible to arrange increases in the average price of a commuter ticket so that they bring about an increase in total passenger miles.

As for the strategy of changing the effect of a change in passenger miles on the price of a commuter ticket, the sign of arrow (1,5), this is certainly feasible: it is simply a matter of deciding to set ticket prices on the basis of passenger miles.

The strategy of changing the effect of a change in passenger miles on the probability of delay, the sign of arrow (1,8), to minus might also be feasible. For example, if work schedules are shifted so that peak demand is lessened, then total passenger miles might

[14] The discussion in this section is based largely on the observations of J. Bigelow and J. DeHaven, and the author gratefully acknowledges their ideas.

be increased, while probability of a delay goes down. Thus, even if increased passenger miles lead to increased commuter ticket prices, the shifting of work schedules could be stabilizing.

Strictly speaking, however, the shift in work schedules or the addition of a new commuter mode are changes in the scenario under which the signs of arrows are defined rather than changes in the signs of the arrows themselves. Alternatively, one might say that they correspond to the introduction of an external *decrease* in the probability of delay variable (8) rather than a change in the sign of arrow (1,8).

Other strategies whose feasibility should be considered are those corresponding to the introduction of an external change at a particular variable. It seems at first glance that the most feasible or "manipulable" variables are fuel economy (2), cost of car (4), and price of commuter ticket (5). However, using the signed digraph G, we see that cost of car is relatively unimportant, because in the signed digraph it has no arrows connecting it to any other variable. Thus, although the strategy of introducing an external change at the cost-of-car variable is feasible, the analysis suggests it will be ineffective. It was pointed out earlier that this situation is altered by replacing variable 4 by a variable "cost of car." The strategy of introducing an external change in this new variable is again feasible, and might very well be effective. To decide, one would have to build a new signed digraph with this as a variable in place of the old variable cost of car.

Feedback loops

Another potentially useful application of the signed digraph is the identification of feedback loops using a constructed signed digraph. It is these loops that contribute so greatly to stability or instability, and knowing these loops can help us to understand the major forces for change present *within* the system. The identification of a feedback loop can be accomplished without knowing the strengths of effects, time lags, or how changes are propagated through the system. Similarly, its character as positive and deviation-amplifying, or as negative and deviation-counteracting, is easy to ascertain without knowing all these things. It is a good rule of thumb that if there are many positive feedback loops, this will lead to increasing deviations and instability. Also, if there are many negative feedback loops, these can lead to increasing oscillations, which is also an unstable situation. If there is a mixture of feedback loops, some positive and some negative, it is not easy to determine what the total effect will be. Indeed, that is one of the problems with analysis of a complex system: there are many interacting processes going on simultaneously. Specification of a rule by which changes are propagated through a system—for example, specification of a pulse process—allows one to analyze the interacting feedback loops. This sort of analysis shows that a positive feedback loop is not always destabilizing. Indeed, if there is already one negative loop, and a second loop has an undecided sign, it might be more stabilizing to make the second one positive than to make it negative. We shall see this in the signed digraph G.

In the case of G, there are three simple feedback loops if arrow (1,5) exists, namely, the cycle from passenger miles to price of a commuter ticket to passenger miles (1,5,1); the cycle from passenger miles to probability of delay to passenger miles (1,8,1); and the cycle from passenger miles to accidents to probability of delay to passenger miles (1,7,8,1). Thus, if this signed digraph accurately reflects the qualitative relations underlying the energy demand system in intraurban commuter transportation, then we have homed in on the basic feedback processes that contribute to instability or can be exploited to attain stability. The cycle 1,7,8,1 is negative; the cycle 1,8,1 is also negative; and the cycle 1,5,1 has undecided sign. It is interesting to note that the sign on arrow (1,5), which stabilizes the situation, is that sign (–) which makes this cycle positive, not negative. We thus have a graphic illustration of the fact that a positive cycle is sometimes stabilizing. Here, it plays the role of counteracting the negative cycle 1,8,1. Indeed, if the undecided sign of (1,5) is taken to be plus, then the undecided cycle 1,5,1 becomes negative, and the situation is not stable unless the sign of arrow (5,1) is changed to make the undecided cycle 1,5,1 positive again, or the sign of arrow (1,8) is changed to make the other cycle (1,8,1) positive.

In any case, identification of the feedback loops is a crucial step in determining the behavior of the system. It can suggest numerous policy alternatives, and aid in identifying stabilizing strategies.

SUMMARY

To summarize, use of a panel of experts to construct a signed digraph to study energy demand or other societal problems is a promising methodology. (It is fairly easy to modify the procedure to obtain estimates of strengths of effects and of time lags, as well.) It is probably not desirable to construct just one signed digraph for the energy demand system or any societal system being studied. Rather, a number of signed digraphs should be built, using different parameters, different methods, or under different scenarios. Conclusions obtained from one signed digraph should be compared and contrasted to those derivable from another signed digraph or, indeed, to conclusions derivable by other methods. Techniques are needed for obtaining consensus signed digraphs from among the various alternatives. However, often it is more interesting to have a class of digraphs to compare than it is to have just one "correct" signed digraph. Indeed, to have faith in the conclusions from analysis of signed digraphs, it is often necessary to see that these conclusions are derivable under various situations or under various methods of analysis.

Once a signed digraph is constructed, it should be returned to the experts for discussion and modifications. Disagreements should be identified and analyzed.

Conclusions from the analysis of the constructed signed digraphs are usually not very interesting for their specific numerical predictions. Rather, they are interesting for their prediction of general geometric trends. Specifically, these are conclusions about stability or instability of the system, and about the type of growth it will exhibit (exponential, oscillatory), and so on. Such conclusions should be regarded as tentative and suggestive, and should be explored using other techniques. These conclusions might become less tentative as more information is added to the digraphs, information such as strengths of effects, time lags, and so on.

Structural analysis of the constructed signed digraph pinpoints possible strategies for modifying the energy demand system and feedback loops that contribute to instability or stability. The enumeration of the possible strategies and of the feedback loops can be done without knowing too much about the complex system being studied—indeed, simply by knowing the arrows and signs joining members of the class of variables. Preliminary analysis of the effects of these strategies and feedback loops can also be made by using just the signed digraphs, without assumptions about how changes are propagated through the system. If such additional assumptions are made, then it can be interesting to perform tests of which strategies are stabilizing, and what combination of signs

on feedback loops leads to stability. Again, conclusions about stability are subject to verification by other techniques. But these conclusions can be of considerable value in aiding us to understand the potential impacts of both public policies and changes in technology or society. In short, the signed digraph can be a useful tool for the policy maker.

CHAPTER EIGHT

Comparative Cognition: Politics of International Control of the Oceans

—Jeffrey Hart

This empirical study begins to explore the relationships between the cognitive maps of different actors, in contrast to the previous studies, all of which analyzed one cognitive map at a time. The relevant political actors in this study are, moreover, highly complex groups of people, including nations, groups of nations, and the international oil industry. Comparative data on the perceived causal linkages of these actors is generated by using the questionnaire technique with a panel of experts who are familiar with a large body of source material on the relevant actors.

The particular problems that this study begins to answer are important for virtually all policy domains:

(1) How does the objective situation of an actor affect its perception (or nonperception) of causal linkages in its policy environment?

(2) How does the internal complexity of an actor affect the consistency between its stated assertions and its policy positions?

*(3) Do actors who agree on policy positions also tend to agree on the causal linkages supporting these positions?**

The subject of this chapter is international cooperation in the exploitation and conservation of ocean resources. In 1969, a United Nations resolution called for the establishment of an international regime to regulate and control the oceans. The objective of this chapter is to consider the feasibility of analyzing the cognitive maps of the principal actors involved in this issue and to obtain in this manner information about the probable outcome of the debate. The actors to be examined include individual nations, groups of nations with common views on the issue, and the world petroleum industry. In this trial study the derivation of

* For acknowledgements, see p. 217.

cognitive maps for a variety of actors is based on the conclusions of a panel of judges. These judges estimated the cognitive maps of the principal actors on the basis of a wide variety of documentary materials. Unlike Roberts' study in Chapter 7 of this book, in the present study the judges estimated others' beliefs, rather than simply their own.

Two types of propositions will be used to analyze the estimated cognitive maps: propositions about the nature of each actor's cognitive map taken as a single, and relatively coherent, entity; and propositions about the differences between pairs of cognitive maps. In addition, the chapter focuses on the subgraphs (called goal structures) of individual cognitive maps formed by the goal variables (variables whose values directly impinge upon the actor's utility). From this analysis, several educated guesses about the final outcome of the 1974–1975 Law of the Sea Conference will emerge.

HISTORY OF THE OCEAN REGIME PROPOSAL

A regime for the control of ocean space was first proposed by the Maltese ambassador to the United Nations, Arvid Pardo, in the General Assembly on August 18, 1967.[1] Pardo's visions of wealth from the oceans, along with his designs for using that wealth to finance a more effective international organization and to redistribute the world's wealth, took most of the members of the United Nations by surprise. The less developed nations were delighted with the idea of benefiting from the exploitation of ocean resources and supported the proposal strongly. The developed nations were not delighted. Vital interests such as military capabilities, energy supplies, and mineral resources were at stake. They wanted more time to think. Nevertheless, in December of 1969, a resolution was passed in the General Assembly reserving the seabed and its resources beyond the limit of national jurisdiction exclusively for peaceful purposes and in the interest of mankind.[2] In 1970, a resolution calling for a new conference on the law of the sea was passed.[3] After several delays, the first session of this conference began in Caracas in June of 1974. Well over a

[1] United Nations, Document A/6840 Add. 2 and A/6695.

[2] This resolution, No. 2574 (XXIV), was passed by a vote of 62 in favor, 28 against, and 28 abstaining.

[3] This was Resolution No. 2749 (XXV) of December 17, 1970.

dozen different proposals were put forth and discussed. Although some progress was made in Caracas toward the narrowing of debate, no agreement was reached, and it is not likely that an agreement will emerge until the next session, scheduled to take place in March 1975, in Vienna. Since the estimation of cognitive maps used in this study was completed prior to the Caracas meeting, it will be possible to examine the results of the analysis in the light of that debate, while still allowing speculation about the final outcome.

GOAL STRUCTURES IN COGNITIVE MAPS

A cognitive map is an actor's belief about the causal relations between pairs of variables in his conceptual inventory. We assume that there are three types of concept variables: (1) policy variables, (2) goal variables, and (3) utility. Goal variables are variables that impinge directly and positively upon the actor's utility variable. We then define a *goal structure* of an actor as the subgraph of that actor's cognitive map which consists of all of his goals and the causal relationships between them. These definitions are illustrated in Figure 8–1. A hypothetical cognitive map is given in the first part of the figure, and the goal structure of this map is given in the second part.

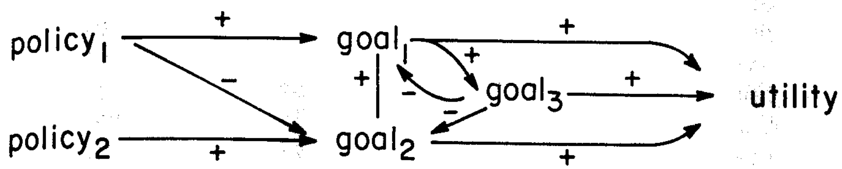
It will sometimes be convenient to represent cognitive maps and their derived goal structures in the form of adjacency matrices (see Bonham and Shapiro in Chapter 6). For illustrative purposes, this is done in the third part of Figure 8–1, where the adjacency matrix of the goal structure is indicated by dotted lines within the larger adjacency matrix of the hypothetical cognitive map.

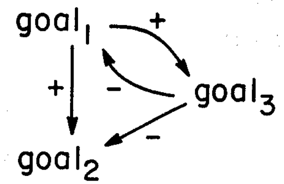
The fact that different actors may have different cognitive maps with respect to the same set of variables suggests that differences in cognitive maps, and especially differences in goal structures, can be used to explain differences in positions taken on policy and goal variables. The basic idea is the notion of "distance" between the goal structures of two actors. Distance will be defined here in terms of an entry-by-entry comparison of the goal adjacency matrices of the two actors. For example, if two goal structures differ in only one entry in their adjacency matrices, their distance from each other is very small. Admittedly, the changing of a single causal link may have a very strong effect on the actor's position,

FIGURE 8–1.

Cognitive Maps and Goal Structures

A Hypothetical Cognitive Map
The Goal Structure of the Hypothetical Cognitive Map
Adjacency Matrix for the Cognitive Map with the Adjacency Matrix for the Goal Structure Shown in Dotted Lines





	p_1	p_2	g_1	g_2	g_3	u
policy₁	o	o	+	−	o	o
policy₂	o	o	o	+	o	o
goal₁	o	o	o	+	+	+
goal₂	o	o	o	o	o	+
goal₃	o	o	−	−	o	+
utility	o	o	o	o	o	o

and, thus, another way of explaining positions would be to investigate the consequences of slight differences in goal structures.

The point is that if actors take different positions on political issues because their cognitions are different, rather than because of some fundamental differences that are independent of cognitive factors, then it may be possible to get actors to agree on some mutually beneficial policy by altering their cognitions. This may be done in a variety of ways, which will be explored in the final section of this chapter. One could, for example, change an actor's cognitions by making him aware of the temptation to simplify causal beliefs. Thus, the analysis of cognitive maps is an abstract, but relatively simple, approach that can help us to understand how international actors come to take positions on international issues, such as the international ocean regime, while also suggesting novel ways of influencing this process.

HYPOTHESES

In order to help clarify the presentation of the data, it is helpful to present the three main hypotheses of this study. As we shall see, these three hypotheses are partly supported and partly refuted by the data. Fortunately, in situations such as these we are able to learn at least as much from our surprises as from our successes.

Hypothesis 1. The developed nations will have denser goal structures than the developing nations.

This is a hypothesis about how the nature of an actor affects its perception of the linkages. It is based on the expectation that the greater research capabilities and wider interests of the developed nations will lead them to perceive more causal linkages than the developing nations perceive with respect to the complex issues of an ocean regime. The formal measure of density of a goal structure is the proportion of all possible linkages that are actually perceived.[4]

Hypothesis 2. The positions taken by the actors will be consistent with their goal structures.

This hypothesis states that even complex actors, such as nations and the oil industry, are consistent, at least on a specialized policy domain such as ocean regime issues. The formal test is that inconsistency can be observed whenever an actor has

[4] The formula for density is $m/n(n-1)$, where m is the number of arrows and n is the number of points in the graph.

a balanced goal structures but does not take positions in accordance with that structure.

Hypothesis 3. Actors with similar positions will have similar beliefs.

This hypothesis states that it is rare for two actors to support the same positions but have widely divergent images of the causal linkages that lead them to their positions. If true, it would mean that alignments of convenience (based on similarity of positions) would also tend to be alignments of perception (based on similarity of beliefs).

In order to test these hypotheses, a methodology was developed to generate data on the goal structures of the relevant actors. After explaining this methodology in the next section, the data will be presented and analyzed. Then implications will be drawn for the potential alignments of the actors and the future of an ocean regime.

METHODS

In order to show how one might gain knowledge about the way the cognitions of international actors affect their positions on political issues, a group of judges was used to estimate the cognitive maps of a small set of actors on a specific issue, the establishment of an international ocean regime. The group consisted of three individuals in the Technology and International Systems Project at the Institute of International Studies in Berkeley, California.[5] All of these individuals are citizens of the United States. They are widely read on the subject of the international ocean regime and international politics in general. They had a self-consciously favorable view toward the regime and Pardo's plan.

The Actors

Two preliminary tasks were the selection of actors and the selection of goal variables. For the actors, there were two criteria. The first was that the actor must be essential to the success of an international ocean regime. The second was that the elements of compound actors share a large number of beliefs about the causal links between variables. Six actors were chosen for this

[5] The individuals are Professor Ernst B. Haas, Peter Cowhey, and Janet Schmidt.

exercise: (1) the United States, (2) the Soviet Union, (3) the other developed nations (the OECD nations minus the United States),[6] (4) the oil-exporting developing nations,[7] (5) the non-oil-exporting developing nations (called the Other LDCs), and (6) the world oil industry.

The Goal Variables

Fourteen variables were chosen by the expert group to be the basis for comparing the cognitive maps of the six actors (see Table 8–1). These variables were selected on the basis that at least one of the actors considered the variable to be a goal.

TABLE 8–1

GOALS PERTAINING TO THE ESTABLISHMENT OF AN OCEAN REGIME

1	Obtaining a high level of petroleum exploitation of the sea bed
2	Obtaining a high level of hard mineral (manganese nodule) exploitation of the sea bed
3	Obtaining the maximum sustainable yield from ocean fisheries
4	Conserving mineral resources (nodules) in the ocean
5	Scheduling the development of land and ocean reserves of petroleum to meet future demand
6	Conservation of ocean fisheries
7	Alleviation of world protein deficiencies
8	Reduction of the potential for conflict over matters pertaining to the ocean
9	Establishment of machinery for resolving conflicts pertaining to the ocean
10	Reduction of military use of the sea bed and deep ocean (emplacement of installations on the sea bed and/or free passage of submarines)
11	Preventing expansion of national jurisdiction into the sea
12	Maintaining the right of innocent passage through territorial waters
13	Preserving the nonliving environment of the ocean
14	Establishing an international regime for ocean space

[6] The states referred to as the OECD states are France, Britain, West Germany, Belgium, the Netherlands, Ireland, Denmark, Spain, Italy, Norway, Sweden, Greece, Portugal, Iceland, Japan, Canada, Australia, and New Zealand.

[7] The major oil-exporting nations are Abu Dhabi, Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, and Venezuela. All are members of OPEC. Ecuador, Gabon, and Trinidad/Tobago are members of OPEC, or have applied for membership, but have not yet become major exporters.

A distinction was made between exploitation of petroleum (goal 1) and hard minerals (2) for a number of reasons: several actors make the distinction; the technology for the two types of exploitation will be very different; and petroleum exploitation is most likely to occur within the territorial waters of nations, while hard minerals are mainly to be found in the deep ocean. A maximum sustainable yield (abbreviated as MSY) for ocean fisheries (3) is obtained when fishing is limited to levels that can be supported by the fisheries without decreasing the stock or future catches. Exploitation of hard minerals, in the form of manganese nodules, can be accompanied by a management system that maintains the exploitation at levels that permit the natural replenishment of the resources. Thus, the conservation of mineral resources (4) was included as a goal variable.

Scheduling the development of land and ocean reserves of petroleum (5) means maintaining a balance between the exploitation of these two forms of petroleum deposits. The United States, for example, wants to develop offshore reserves as an alternative to imported oil, even though offshore oil is much more expensive than oil from land reserves. In addition, the United States maintains land reserves in case of war or emergency, since offshore reserves would be more vulnerable. The goal of conserving fisheries (6) is taken here to include management techniques such as stocking and mariculture, as well as the more limited techniques of setting quotas, issuing licences, and inspecting fishing grounds. A separate goal of preserving the nonliving environment (13) was included, since many of the actors do not consider fishery conservation to involve management of the nonliving environment. For example, a fishery management regime would be expected to react to an oil spill, but not to prevent it. Alleviating world protein deficiencies (7) is a straightforward goal that could be achieved through the use of fish meal for animal feed, through the direct consumption of fish, or possibly from the synthesis of protein from petrochemical by-products.

The goals concerning conflict or potential conflict are: reducing potential conflict over matters pertaining to the ocean (8), the establishment of machinery for resolving conflicts pertaining to the ocean (9), and the reduction of military uses of the ocean (10). It was assumed that conflict reduction could take place on an *ad hoc* basis without extensive machinery—that is, without formal organizations designed to perform such conflict-resolving tasks as mediation, arbitration, inspection, or peace keeping.

There are two goals concerning national control over adjacent waters. Preventing expansion of national jurisdiction into the sea (11) does not have to affect navigation. It may be limited to jurisdiction over mineral or living resources. Another goal (12) is innocent passage, involving the rights of ocean vessels to pass through territorial waters of other nations without interference.

Finally, there is the variable of establishing an international regime for ocean space (14). It was assumed that this regime would have the following minimal properties: (1) the regime would include standing machinery, that is, a formal organization with a staff and a budget; (2) this organization would have jurisdiction over more than one of the general domains of mineral resources, living resources, conflict resolution, and control over national waters; and (3) some area of the ocean would be specified as res communis, to be explored, if at all, for the benefit of all mankind. Not all of the current proposals for an international regime meet these criteria, but the group of judges had the Pardo proposal uppermost in their minds.

Estimating the Goal Structures

After selecting the actors and the variables, the group of judges was asked to fill out a goal adjacency matrix, similar to the one in Figure 8–1, for each of the actors. Members of the group consulted an extensive set of fifty-one documentary sources (a list of which may be obtained from the author on request). These documents included position papers, transcripts of debates, and commentaries on the evolution of the law of the sea by legal scholars and social scientists. In an initial trial run, good intercoder agreement was obtained.[8] Because of limitations of time, expertise, and mental capacity, it was impossible for each member of the group to fill out a matrix for each actor. Therefore, the group subsequently arrived at a group consensus by discussion. This was very time-consuming, but the payoff in accuracy was judged to be more important than a more complete test of intercoder reliability.

The end result of this process is displayed in Tables 8–2 through 8–9. The symbols +, −, a, and cd in Tables 8–3 through

[8] In the initial run, goal structures for the two superpowers were estimated. Over 80 percent of the entries of the goal adjacency matrices were in agreement for each pair of coders. Most discrepancies were the result of a zero entry in one matrix and a non-zero entry in the other.

TABLE 8–2

POSITIONS TAKEN ON THE OCEAN GOALS AND THE RELATIVE SALIENCE OF GOALS FOR EACH ACTOR

	U.S.		USSR		OECD		Oil exporters		Other LDCs		Oil industry	
Goals	P[a]	S[b]	P	S	P	S	P	S	P	S	P	S
Oil exploitation	+	m	o	l	+	h	+	h	−	m	+	h
Nodule exploitation	+	m	+	m	+	m	o	l	+	m	o	l
MSY (sustainable yield)	−	m	+	h	+	m	o	l	+	h	o	l
Nodule conservation	−	l	−	l	−	l	o	l	+	m	−	m
Scheduled development	+	l	+	l	−	h	+	h	o	l	−	m
Fishery conservation	+	m	−	m	+	m	o	l	−	h	o	l
World protein	+	l	+	l	+	l	o	l	+	h	o	l
Conflict reduction	+	m	+	m	+	h	o	l	−	h	+	h
Conflict machinery	+	l	−	l	+	m	−	h	?		−	l
Reduction of military	−	h	−	h	a[c]	m	+	h	+	m	o	l
Prevention of expansion	+	m	+	h	+	h	−	h	−	h	−	h
Innocent passage	+	h	+	h	+	h	−	h	−	h	+	h
Nonliving environment	+	h	o	l	+	m	−	l	+	m	−	l
International regime	+	m	−	l	a[d]	m	o	l	+	h	−	h

[a] P stands for "position," and + = favor or support, − = oppose, o = no position or neutral, and a = ambiguous (some support and some oppose).

[b] S stands for "salience," and l = low, m = medium, and h = high.

[c] Britain and France are opposed to reduction of military use of the oceans, since they have substantial naval forces and some submarines. Australia and New Zealand would also oppose reduced military use, since they depend on American naval forces to deter Chinese or Russian aggression in that part of the world. The other OECD members generally favor demilitarization in world politics.

[d] Some OECD nations, such as Canada, are in favor of limited international regimes, while others are opposed.

TABLE 8–3

GOAL ADJACENCY MATRIX FOR THE UNITED STATES

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Oil exploitation	1	o	+	—	—	cd	—	a	—	+	+	—	—	—	—
Nodule exploitation	2	+	o	o	—	o	o	o	—	+	a	—	—	—	—
MSY (sustainable yield)	3	o	o	o	+	o	—	+	—	+	o	—	+	o	cd
Nodule conservation	4	—	—	o	o	a	o	o	—	+	o	o	+	+	+
Scheduled development	5	+	o	o	o	o	o	o	—	+	o	—	—	+	+
Fishery conservation	6	—	—	cd	o	o	o	+	—	+	o	—	+	+	+
World protein	7	+	o	+	o	+	o	o	cd	o	o	cd	o	o	o
Conflict reduction	8	+	+	o	+	+	o	o	o	—	+	+	+	o	cd
Conflict machinery	9	+	+	o	+	o	+	o	+	o	—	+	+	o	o
Reduction of military use	10	o	—	o	o	o	o	o	—	o	o	o	o	+	o
Prevention of expansion	11	—	—	a	o	—	o	o	—	+	—	o	—	o	—
Innocent passage	12	+	+	—	o	+	+	+	—	+	—	+	o	—	+
Nonliving environment	13	—	—	o	+	—	+	o	—	+	+	o	—	o	+
International regime	14	+	+	+	+	+	+	+	+	+	—	—	+	+	o

TABLE 8–4

GOAL ADJACENCY MATRIX FOR THE SOVIET UNION

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Oil exploitation	1	o	+	—	—	cd	—	a	—	+	+	—	—	—	o
Nodule exploitation	2	+	o	—	—	o	o	o	—	+	a	—	—	—	—
MSY (sustainable yield)	3	o	o	o	+	o	—	+	—	+	o	+	+	o	cd
Nodule conservation	4	o	—	o	o	o	o	o	—	+	o	o	+	+	+
Scheduled development	5	o	o	o	o	o	o	o	—	+	o	—	—	o	+
Fishery conservation	6	o	o	cd	o	o	o	+	—	+	o	—	+	+	+
World protein	7	+	o	+	o	+	o	o	cd	o	o	cd	o	o	o
Conflict reduction	8	+	+	o	+	+	o	o	o	—	+	+	+	o	cd
Conflict machinery	9	o	o	o	o	o	o	o	o	o	o	+	+	o	o
Reduction of military use	10	o	—	o	o	o	o	o	—	o	o	o	o	+	o
Prevention of expansion	11	—	—	a	o	—	o	o	—	+	—	o	—	o	—
Innocent passage	12	+	+	+	o	+	o	+	o	+	—	+	o	—	+
Nonliving environment	13	—	—	o	+	—	+	o	—	+	+	o	—	o	+
International regime	14	+	+	+	+	+	+	+	+	o	—	—	+	+	o

TABLE 8–5

GOAL ADJACENCY MATRIX FOR THE OECD STATES
(MINUS THE U.S.)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Oil exploitation	1	o	+	—	—	—	—	cd	+	—	+	—	+	—	—
Nodule exploitation	2	+	o	—	—	—	—	o	+	—	+	—	—	—	—
MSY (sustainable yield)	3	—	—	o	+	—	+	+	o	+	+	o	o	o	o
Nodule conservation	4	o	—	o	o	o	o	o	o	+	+	+	+	+	+
Scheduled development	5	+	o	o	o	o	o	o	o	o	o	—	o	o	—
Fishery conservation	6	o	o	+	o	o	o	+	o	+	+	o	o	o	cd
World protein	7	+	o	+	o	o	o	o	o	o	o	+	+	o	+
Conflict reduction	8	+	+	+	+	o	+	o	o	+	+	+	+	o	cd
Conflict machinery	9	+	+	+	+	o	+	o	+	o	+	+	+	o	cd
Reduction of military use	10	+	+	+	+	o	+	o	+	o	o	+	+	+	+
Prevention of expansion	11	—	o	+	o	—	o	o	+	o	o	o	+	—	+
Innocent passage	12	+	+	+	o	+	o	a	+	—	—	+	o	—	cd
Nonliving environment	13	—	—	+	+	—	+	+	+	+	+	—	—	o	+
International regime	14	o	—	+	+	o	+	+	+	+	o	—	+	o	o

TABLE 8–6

GOAL ADJACENCY MATRIX FOR THE OIL EXPORTERS

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Oil exploitation	1	o	+	—	o	+	o	+	+	o	+	—	—	o	cd
Nodule exploitation	2	+	o	o	—	+	o	o	—	o	o	—	—	—	—
MSY (sustainable yield)	3	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Nodule conservation	4	o	o	o	o	o	o	o	+	+	+	+	+	+	cd
Scheduled development	5	+	o	o	o	o	o	+	+	o	+	—	—	+	o
Fishery conservation	6	o	o	o	o	o	o	o	o	o	o	o	o	o	o
World protein	7	+	o	o	o	o	o	o	o	o	o	o	o	o	o
Conflict reduction	8	+	o	o	o	+	o	o	o	o	o	o	o	o	o
Conflict machinery	9	+	o	o	o	+	o	o	o	o	o	o	o	o	o
Reduction of military use	10	+	+	o	o	+	o	o	o	o	o	+	+	o	+
Prevention of expansion	11	+	+	o	o	—	o	o	—	—	—	o	—	o	—
Innocent passage	12	+	o	o	o	—	o	o	—	—	—	o	o	o	o
Nonliving environment	13	—	o	o	o	—	o	o	—	o	+	—	—	o	+
International regime	14	o	—	o	o	o	o	o	+	+	+	o	o	+	o

TABLE 8–7

GOAL ADJACENCY MATRIX FOR THE OTHER LDCS

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Oil exploitation	1	o	+	—	—	—	—	o	—	—	—	—	—	—	—
Nodule exploitation	2	+	o	—	—	o	—	—	—	—	—	—	—	—	—
MSY (sustainable yield)	3	—	—	o	o	o	+	+	—	+	+	o	—	+	cd
Nodule conservation	4	o	—	o	o	+	o	o	+	+	+	+	+	+	+
Scheduled development	5	+	o	o	o	o	o	o	o	o	o	—	o	o	cd
Fishery conservation	6	o	—	+	+	o	o	+	—	+	+	o	o	+	+
World protein	7	o	—	+	o	o	o	o	+	o	o	o	+	+	+
Conflict reduction	8	o	o	+	+	+	+	o	o	+	+	o	o	o	+
Conflict machinery	9	o	o	+	+	+	+	o	+	o	+	o	o	o	cd
Reduction of military use	10	o	o	+	+	+	+	o	+	+	o	o	o	o	+
Prevention of expansion	11	+	+	—	—	—	o	—	—	—	—	o	—	—	+
Innocent passage	12	+	+	—	—	—	—	o	—	—	—	—	o	—	cd
Nonliving environment	13	—	—	+	+	o	+	o	o	+	+	o	—	o	+
International regime	14	+	—	+	+	+	+	+	o	o	+	+	—	+	o

TABLE 8–8

GOAL ADJACENCY MATRIX FOR THE OIL INDUSTRY

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Oil exploitation	1	o	+	o	o	+	o	+	+	—	o	—	+	—	—
Nodule exploitation	2	+	o	o	—	+	o	o	+	—	o	—	+	—	—
MSY (sustainable yield)	3	o	—	o	o	—	o	+	o	o	o	o	—	o	o
Nodule conservation	4	o	—	o	o	—	o	o	o	o	o	o	—	o	o
Scheduled development	5	cd	+	o	o	o	o	o	+	—	o	—	o	o	o
Fishery conservation	6	—	—	o	o	o	o	o	o	o	o	o	o	o	o
World protein	7	o	o	o	o	o	o	o	o	o	o	o	+	o	o
Conflict reduction	8	+	+	o	o	+	o	o	o	o	o	o	+	o	—
Conflict machinery	9	o	o	o	o	o	o	o	o	o	o	—	—	o	o
Reduction of military use	10	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Prevention of expansion	11	—	—	o	o	—	o	o	—	o	o	o	o	o	o
Innocent passage	12	+	+	o	o	+	o	+	+	o	—	o	o	o	—
Nonliving environment	13	—	—	o	o	—	o	o	—	+	o	—	—	o	o
International regime	14	—	—	o	o	—	o	o	—	—	o	—	—	+	o

TABLE 8–9

GOAL ADJACENCY MATRIX FOR THE GROUP OF JUDGES

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Oil exploitation	1	o	+	—	o	cd	—	a	—	+	a	—	—	—	+
Nodule exploitation	2	+	o	a	—	+	—	o	—	+	+	—	—	—	—
MSY (sustainable yield)	3	—	—	o	+	o	+	+	—	+	—	—	+	o	cd
Nodule conservation	4	o	cd	+	o	o	o	o	—	+	o	+	+	+	+
Scheduled development	5	+	+	o	o	o	o	o	—	+	o	—	o	+	o
Fishery conservation	6	—	—	+	+	o	o	+	—	+	o	+	+	+	+
World protein	7	o	o	+	o	o	+	o	+	o	o	o	o	o	o
Conflict reduction	8	+	+	+	+	+	+	o	o	cd	+	+	+	+	cd
Conflict machinery	9	+	+	o	+	o	+	o	+	o	+	+	+	o	+
Reduction of military	10	+	+	+	o	o	+	o	+	o	o	+	+	+	+
Prevention of expansion	11	—	—	o	o	—	a	o	+	+	a	o	+	a	+
Innocent passage	12	+	+	+	+	+	+	o	—	+	—	+	o	—	+
Nonliving environment	13	—	—	+	+	—	+	o	—	+	+	—	—	o	+
International regime	14	+	—	+	+	+	+	+	o	+	o	+	+	+	o

8–9 stand for positive, negative, ambiguous, and curvilinear downward causal relations between variables. A curvilinear downward relation between goals x and y means that the realization of goal x facilitates that of goal y only if partial success is obtained in goal x; otherwise, goal y is blocked or impeded. This means that intermediate values of x result in high values of y, and extreme values of x (either high or low) result in low values of y. The curvilinear downward relation was included in this study because the group of judges consistently expressed a need for a curvilinear relation to supplement the monotonic positive and negative relations. After the curvilinear downward relation was explained to the group, they seemed satisfied that it would solve most of the problems they were having in estimating the causal beliefs of the actors. The fact that the group saw no need for using the curvilinear upward relation is interesting in itself, and could bear further study.

The group of judges was then asked to estimate the positions taken on each of the goal variables and the salience of the variable. The results, given in Table 8–2, correspond to the last column of the causal adjacency matrix of the cognitive map in Figure 8–1. The sequence of estimation—goal structure first and positions second—was thought to have a significant impact on the results. Considerable knowledge about the positions of the actors was gained in the process of estimating their goal structures.

At no time were the members of the group of judges informed of the three central hypotheses of this study. None of the members of the group had any previous exposure to graph theory or the analysis of cognitive maps. Nevertheless, the group knew that one of the purposes of the exercise was to use differences in cognitions to explain why certain actors favored an international ocean regime and others did not. Since the data here is purely judgmental, the separation of hypothesis and estimation was considered important. To allow for a test of the possibility that the group's estimates of perceived causal links were too clearly related to their personal estimates, the group was also asked to give their own ideas about the causal relations among variables (see Table 8–15 below).

The fact that the expert group's goal structure most closely resembled that of the United States may cast some doubt on the impartiality of the group. The fact that their goal structure more closely resembled the goal structure of the non-oil-exporting developing nations than those of the oil industry or the oil exporters, however, suggests that this resemblance was more a function of the comparative densities of the structures than of ethnocentricity or differences of opinion on the sign of specific causal links. That is, most differences between goal structures involved the expert group's estimating a causal link where an actor does not. Thus there are several possible explanations for the variance among distances from the expert group's goal structure: (1) bias on the part of the expert group; (2) the density of the actor's goal structure; and (3) lack of information on the part of the expert group about the causal beliefs of the actor.

Several things may be done to increase one's confidence in the estimated goal structures: (1) the use of experts from a number of different countries; (2) the use of a more context-free method of estimating goal structures (see Roberts in Chapter 7); and (3) more extensive checks on the reliability of individual estimates. Each of these would have involved more time and expense than this trial study allowed. Nevertheless, it is believed that the use of experts to estimate the beliefs of international actors is both feasible and desirable for many research purposes. Transcripts of governmental strategy sessions are not always available. The actors are not always accessible for interviews. The probable alternative to the procedures used here would be to increase the number and variety of experts estimating goal structures, or to simplify the task by limiting the number of goal variables so that the time required of the actors, or their representatives, would be minimized.

The analysis of all the estimated goal structures will now be undertaken from both a separate and a comparative basis. The maps will be separately analyzed in terms of complexity, density, imbalance, and inconsistencies relative to subgraphs of salient goals; the analysis will allow a test of the first two hypotheses. The comparative analysis focuses on the patterns of similarities and differences between actors with respect to both their causal beliefs and their policy positions; the comparative analysis will allow a test of the third hypothesis. Throughout both analyses it will be assumed that the judges were accurate in estimating the actors' beliefs. The importance of this assumption will be reexamined in the section on "Explanations of Cognitive Inconsistencies."

ANALYSIS OF THE GOAL STRUCTURES OF THE SEPARATE ACTORS

The most striking feature of the goal structures estimated by the expert group is their relatively high complexity. They are not balanced; they are not acyclic; and they have relatively high density. The structures are too complex to be readily comprehended when presented in pictorial form. Even the structure with the lowest density, the oil industry's goal structure, has 66 of a possible 182 linkages, or 36 percent (see Table 8–10).

The first hypothesis can now be evaluated. The developed nations do indeed have relatively dense goal structures, as shown in Table 8–10. The United States, the Soviet Union, and the OECD states perceive causal linkages between the 14 goal variables at levels of 68 percent, 60 percent, and 80 percent, respectively. The Oil Exporters, on the other hand, perceive that only 37 percent of the possible linkages exist. The only anomaly is that the Other LDCs perceive more linkages than the two superpowers.

TABLE 8–10

DENSITY OF GOAL STRUCTURES
(percent)

U.S.	*USSR*	*OECD*	*Oil exporters*	*Other LDCs*	*Oil industry*	*Expert group*
68	60	80	37	69	36	76

With only one exception (the Other LDCs) the density of substructures of highly salient goal variables is greater than the density of the whole structure (see Table 8–11). The substruc-

TABLE 8–11

DENSITY OF SUBSTRUCTURES OF HIGHLY SALIENT GOALS
(percent)

U.S.	*USSR*	*OECD*	*Oil exporters*	*Other LDCs*	*Oil industry*
83	67	90	77	63	75

tures of the highly salient goal variables were, therefore, more dense than the substructures of less salient goals. Such a result suggests that the salience of goals is positively associated with the density of the goal structure. This conclusion may help to explain why the developing nations that do not export oil have goal structures with higher densities than was first expected. Even though they do not have great research capabilities, many of the goals included in this analysis were salient to them. A supplementary explanation would be that the Pardo proposal made them aware of more causal linkages.

Substructures of Salient Goals

In view of these findings of differences between the actors, as well as the initial investigation of the density of the goal structures, it is possible to proceed to test the second hypothesis about the tendency to hold positions that are consistent with beliefs. None of the goal structures in Tables 8–3 to 8–9 is perfectly balanced. This a rather unusual finding, for which explanations will be proposed. In any case, positions may be consistent only to a limited degree with goal structures that are not balanced. One kind of limited consistency will be explored by focusing on the substructures of highly salient goal variables (see Figure 8–2). These substructures are substantially more balanced than the entire structures, but there are still only two perfectly balanced substructures, those of the United States and the oil exporters.

Strangely enough, even though these two are balanced, the United States' substructure provides evidence that the positions taken on goal variables may be inconsistent with even *balanced* goal substructures. The United States should be either in favor of innocent passage and against both protection of the nonliving environment and reduced military use, or vice versa. Table 8–2 demonstrates, however, that the United States is for innocent passage and protection of the nonliving environment, while being against reduction of military use of the oceans. Possible explanations for this will be explored later.

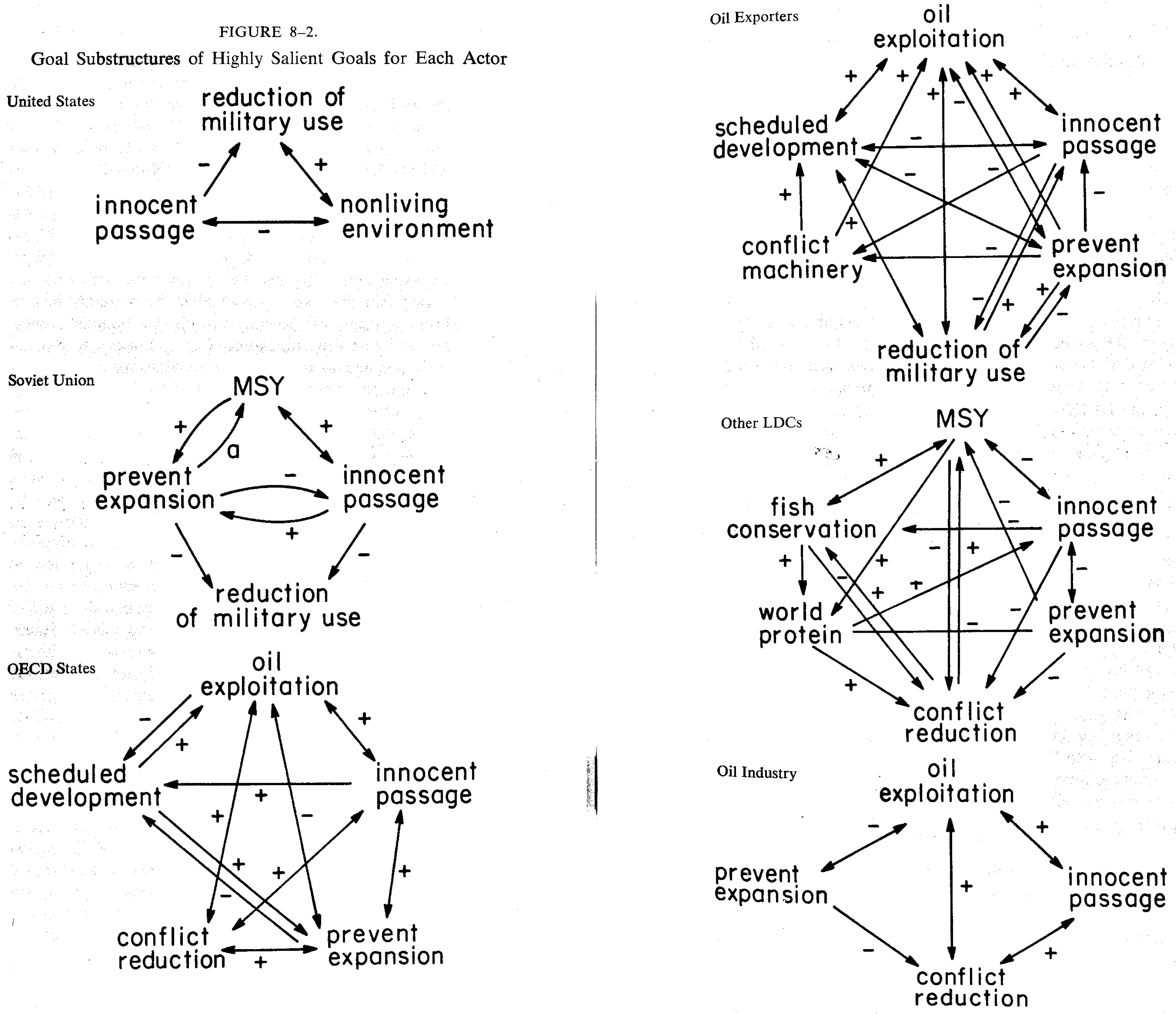
The oil industry, on the other hand, has taken positions consistent with the substructure of its most salient goals: it favors oil exploitation, conflict reduction, and innocent passage, but opposes preventing the expansion of national jurisdictions. This opposition to limiting expansion, consistent with the perceived incompatibilities between preventing expansion and reducing conflict or increasing offshore exploitation, has led the oil industry to take the same position on expansion that most of the developing nations have chosen. Some observers have commented on a possible alliance between the developing nations and the oil companies. Judging from the full range of goals and from perceived linkages, such an alliance is extremely unlikely unless limited to this issue.

The developing nations (minus the oil exporters) favor a maximum sustainable yield for fisheries, conflict reduction, and alleviation of world protein deficiencies, while opposing fishery conservation (primarily the position of fishing LDCs), innocent passage, and limiting expansion. The last two goals were both opposed despite the fact that they were perceived to be mutually incompatible. This inconsistency is partially a result of nationalist domestic pressures, and partly an indication of an inclination to bargain with innocent passage in order to get concessions from major powers to expand their national jurisdictions.

Other actors also permitted the existence of imbalance within goal structures and inconsistencies between positions and structures. The Soviet Union wants to prevent the expansion of national jurisdictions for reasons concerned with fishing. At the same time, it is fully aware of the possibility that preventing expansion may result in decreased willingness to allow military or scientific vessels to operate in national waters. Even so, they do not view innocent passage to be incompatible with the limitation of expansion of national jurisdictions. In these inconsistent perceptions, they are in perfect agreement with the United States, although the issue of preventing expansion is much less salient for the United States. The crucial question for the establishment of an ocean regime is whether the superpowers will be willing to trade some expansion of jurisdictions for guarantees of innocent passage. Although the superpowers share perceptions of the linkages involved, they do not consider the goals to be equally salient. This difference may impede efforts to negotiate, since the United States may be more flexible on the question of expansion than the Soviet Union.

For the oil exporters, the goals of high oil exploitation, scheduled development, establishment of conflict machinery, and reduction of military use of the oceans are all compatible. It is surprising, therefore, that the expert group believed them to be opposed to conflict machinery, while in favor of the other three goals. There is a substantial amount of asymmetry and inconsistency in the substructure, however, which could affect the choice of posi-

FIGURE 8–2.
Goal Substructures of Highly Salient Goals for Each Actor



tions. Positive-negative pairs of linkages include those between oil exploitation and preventing expansion, oil exploitation and innocent passage, innocent passage and reduction of military use, and reduction of military use and preventing expansion. Several of these asymmetries may be attributable to conflicts between domestic economic goals and the foreign policy objectives of the Arab oil exporters. For example, the Arab oil exporters realize that preventing expansion may increase offshore oil exploitation. Even so, they preferred to deny the right of nations who sympathize with Israel to use their national waters, especially the Straits of Tiran and the Suez Canal. In addition, the oil exporters may believe that unregulated offshore oil exploitation will be of greater benefit to the oil companies or the major consumers than to them. Thus, they would like to convey to the rest of the world the idea that increased offshore oil exploitation can take place only in the context of expanded national jurisdictions.

For the OECD nations, a high degree of compatibility is perceived among the goals of conflict reduction, innocent passage, and preventing expansion. The incompatibilities that exist are due to the goals of scheduled development and oil exploitation. High oil exploitation means "scheduled development" for them, since their main domestic reserves are offshore, in the North Sea. They are opposed to what the United States and oil-producing states understand of scheduled development, which requires maintaining an approximately constant ratio between onshore and offshore reserves. Their opposition derived from the policy's implication of continued dependence on Middle East oil at levels that they would prefer not to maintain. They favor intensive offshore oil exploitation, not because it is compatible or incompatible with scheduled development, but because it reduces their dependence on oil imports. Although they believe that preventing expansion goes along with preserving innocent passage and reducing conflict in the oceans, they also believe, on the basis of North Sea experiences, that oil exploitation is inconsistent with limiting expansion. Yet, despite this perceived incompatibility, they take the position of favoring oil exploitation, preventing expansion, preserving innocent passage, and reducing conflict.

There is, generally, a tendency for actors to take positions consistent with the substructures of their most salient goals, but it is stronger for some actors than for others. In this study, the oil industry demonstrated the strongest tendency.

Explanations of Cognitive Inconsistencies

There is a number of possible explanations for imbalance and inconsistencies; yet reasons are generally found at two levels. First, there may be methodological errors in the research design. The most obvious is that the group of judges might not have accurately estimated the goal structures or the positions of the actors. They may have overestimated the complexity of causal beliefs of some actors, while underestimating the complexity of others. For example, the consistency of the oil industry's positions may be the result of the group's lack of information on the beliefs of the oil companies. They may have compensated for this lack of information by estimating what the oil industry's position *should* be, rather than what it is. This might bias their estimates in the direction of balance, which would increase the opportunity for inconsistencies between the goal structure and the position of a given actor. But notice, too, that lack of information about positions could also work to lessen observed inconsistencies if the judges let their estimates of an actor's beliefs affect their estimates of the actor's position, or vice versa.

Another possibility is that the actors consciously concealed their cognitions, making the accurate estimation of cognitive maps very difficult. It has been suggested above, however, that the attempt to convince others that a particular causal relation exists between two goals is an important part of the political process, especially in bargaining. Even if the actor does not really believe that the relation exists, he may be bound to behave as if it did.

Second, aside from measurement error or deception, and assuming the research design to be valid, explanations may be drawn from data based on other supporting evidence. The most convincing explanation of the inconsistencies uncovered is that nations simply do not feel strongly pressed to maintain positions that are consistent with their goal structures. On the contrary, they are often forced to take highly inconsistent positions for domestic political reasons, or to justify their positions by altering their causal beliefs, rather than vice versa. Alain Joxe (1966), in a pioneering article on the inconsistency of West German foreign policy objectives, was the first to suggest that a high level of inconsistency may result from domestic pressures. In a related work, Wolfram Hanrieder (1967, pp. 7–8) distinguished between "consensus," internal agreement on goals, and "compatibility," the logical consistency of a set of goals that is dependent on the conditions prevailing in the international system. He hypothesized that consensus may be positively associated with compatibility. In other words, professing incompatible goals may make it difficult to win agreement for a particular set of policies. Since the West Germans were forced to maintain incompatible goals during the Cold War (e.g., the reuniting of Germany and the maintenance of the alliance with the United States) due to the bipolarized nature of the international system, they were bound to experience a certain amount of domestic dissension. Their ability to pursue incompatible goals during this period testifies to the ability of national actors to tolerate inconsistency.

Analysis at the national level indicates that the sources of inconsistency are various. Several sources suggested above were: the desire on the part of an actor to impress upon others a threat that certain undesirable consequences will result from the pursuit of goals that are contrary to its interests; pressure from domestic groups of various sorts to take positions that are not considered to be consistent with links between goals that are perceived by central decision-makers; and conflicts between primarily internal goals, such as economic development, and primarily external ones, such as pursuing a hostile policy toward another sector.

On the individual, cognitive level, the sources of imbalance and inconsistency may be differential abilities to process complex information or to tolerate imbalance and ambiguity. It may also be a function of differential levels of access to technical information. People who have a low tolerance for ambiguity are likely to perceive balanced goal structures and take positions consistent with those structures. People with greater access to technical information are more likely to have goal structures that take into account the most recent technological factors. These structures may be more or less balanced than those of individuals with less access to information, depending upon the nature of that information. For example, scientists at Woods Hole Observatory are more likely to know about the recent technological aspects of ocean drilling than government officials in Burma. Knowledge of these details may have an important effect on perceptions of linkages between oil exploitation and other goals. Since the goal structures and positions estimated above were imputed to international actors (generalized aggregates composed of numerous individuals), and since the individuals within each actor may have different levels of access to information and differential abilities to tolerate ambiguity, the goal

structure of the actor may be imbalanced because of the compromises that must be made among individuals in order to obtain an overall internal consensus.

Finally, it is possible that the nature of the situation contributes to the inconsistency between goal and positions. The oceans are used for a large number of purposes, many of which are in conflict with one another. Because of the increasing levels of usage and awareness that the oceans are part of a global ecosystem, ocean goals are becoming more interrelated. This high level of complexity and conflict among goals makes it harder for actors to decide on a consistent set of positions. The low salience of the ocean debate also contributes to the inconsistencies between goal structures and positions. Except during periods of crisis, such as the *Torrey Canyon* and Santa Barbara oil spills, the issues of ocean exploitation and preservation are not salient compared to domestic issues such as the health of the economy, the electoral process, or problems of succession. However, the low salience of the debate also creates opportunities for scientific and technical experts to affect policies by changing perceptions of links between goals. Scientifically informed perceptions may be less subject to over-simplification than perceptions based on the policy makers' experiences.

Comparative Analysis of the Goal Structures

The pattern of similarities and differences between actors will now be compared, first in terms of the beliefs that compose their goal structures. The resulting measure is called the "matrix distance" between two given actors because it is based on a comparison of the adjacency matrices of the goal structures of the actors. A second way to examine the pattern of similarities and differences between actors will be to analyze the positions they take for or against each of the goal variables. This will give a "position distance" measure for each pair of actors. The relationship of these two measures over the entire set of actors will allow a test of the third hypothesis, concerning whether alignments of convenience are likely to be alignments of perception as well.

Such comparative measures are important for three reasons. First, they augment comparisons of positions taken on the ocean regime. Second, they enable the analyst to estimate potential alignments. Third, they support predictions on outcomes in light of changing beliefs. Each of the two measures will be defined and the computations involved explained. Tables showing results for each pair of actors will be presented. Finally, a comparison among the methods for validity and usefulness will be made.

Measuring Differences in Goal Structures

The matrix distance between two actors is a measure of the difference between the goal structures of two actors. It takes into account not only the number of causal links on which the actors disagree, but also the magnitude of each disagreement.

For example, a comparison of the United States to the Soviet Union illustrated the matrix distance measure. Each of the entries of the goal structures (Tables 8–3 and 8–4) were compared, and the results are summarized in Table 8–12. The range of the set

TABLE 8–12

AGREEMENT OF ENTRIES IN GOAL STRUCTURES: THE UNITED STATES AND THE SOVIET UNION

		United States					
		o	+	−	*cd*	*a*	*Total*
Soviet Union	o	57	8	6	0	1	72
	+	0	56	2	0	0	58
	−	1	0	42	0	0	43
	cd	0	0	0	6	0	6
	a	0	0	0	0	3	3
Total		58	64	50	6	4	182

of possible relationships is positive (+), negative (−), none (0), curvilinear downward (cd), and ambiguous (a). In two cases the Soviet Union perceived goals to be compatible that the United States considered incompatible. They were MSY (Maximum Sustainable Yield in fisheries) and preventing expansion; and innocent passage and MSY. In fifteen cases the United States perceived a linkage that the Soviet Union did not, and in one case the Soviet Union perceived a negative linkage not perceived by the United States. To determine the matrix distance between the goal structures of the two actors, the following weighting factors are used:

(1) 0 = linkages are equal;

(2) ½ = one linkage is curvilinear downward, and the other is positive or negative;

(3) 1 = all unequal linkages, neither (2) nor (4);

(4) 2 = one linkage is positive, the other is negative. The matrix distance is computed by first determining the weighting factor for each pair of goal variables of the two actors. Then a summation of the weighting factors is made. For example, the matrix distance of the United States and the Soviet Union is $1\times(8+6+1+1)+2\times(2)=20$.

The second measure, position distance, compares two actors by concentrating on the positions of the actors over the entire range of ocean goals. This measure takes into account the salience of the goal for each actor and the magnitude of the difference between the positions of the actors on the goal. Position distance for a pair of actors is computed in the following manner:

(1) Each actor is given a score of from 3 to −3 on each goal, depending on support or opposition and salience:

3 = support, high salience
2 = support, medium salience
1 = support, low salience
0 = no position
−1 = oppose, low salience
−2 = oppose, medium salience
−3 = oppose, high salience.

(2) Absolute differences between scores on the same goals for a given pair of actors were summed and divided by the maximum possible difference (in most cases, $6\times 14=84$). For example, the absolute difference between the United States and the Soviet Union on oil exploitation is $|2-0|=2$.

The results of the calculations for the two measures, matrix distance and position distance, are summarized in Tables 8–13 and 8–14. Using these results, it is possible to make a comparative

TABLE 8–13

MATRIX DISTANCE SCORES FOR EACH PAIR OF ACTORS

	U.S.	*USSR*	*OECD*	*Oil exporters*	*Other LDCs*	*Oil industry*
Soviet Union	20					
OECD	71	96				
Oil exporters	110	102	104			
Other LDCs	108	109	84	108		
Oil industry	112	106	107	74	140	
Group of judges	69	76	71	124	95	128

TABLE 8–14

POSITION DISTANCE SCORES (times 100)

	U.S.	USSR	OECD	Oil exporters	Other LDCs
Soviet Union	26				
OECD [a]	21	28			
Oil exporters	50	45	50		
Other LDCs [b]	60	47	54	40	
Oil industry	38	33	31	26	60

[a] Since the OECD states differed among themselves on the issues of reducing military use and the international ocean regime, a range of scores was calculated and the midpoint used. An error factor of around 10 percent may be involved.

[b] Since this actor's position on conflict machinery was not known, the total difference score was divided by 78=(6×13) instead of 84.

analysis between the goal structures of pairs of actors. Before undertaking the comparative analysis, the relationship between the measures will be explored.

Examination of the results of the matrix distance and position distance measures shows that the scores generated by these measures tend to be positively correlated. The rank order (gamma) correlation between matrix distance and position distance is .46. The positive correlation is clearly shown in Figure 8–3. This result

FIGURE 8–3.

Possible Structures of Cooperation-Conflict in the Ocean Debate

Matrix Distance [a]
Position Distance [b]

[a] Rules for drawing lines were:
▬ if matrix distance less than 75
— if matrix distance greater than 75 but less than 100

[b] Rules for drawing lines were:
▬ if position distance less than 30
— if position distance greater than 30 but less than 38

supports hypothesis three, that actors with similar positions will tend to have similar beliefs about linkages between goals.

Comparison among Actors and Potential Coalitions

Given these relationships between the two measures, a comparative analysis of the actors can be undertaken. The objective of the analysis is to locate *groupings of goals* that could result in *coalitions of actors* on the issue of establishment of an ocean regime. The three pairs of actors with the lowest matrix distances are the same as the three pairs of actors with the lowest position distances: oil exporting nations and the oil industry; the two superpowers; and the United States and the OECD. This finding coincides with the results from the other measures. The pair with the greatest matrix distance, Other LDCs and the oil industry, also has a large position distance.

The relationships demonstrated by the measures of goal variables suggest that coalitions between the following pairs of actors may arise: the United States and the Soviet Union; the United States and the OECD; the oil-exporting nations and the oil industry.

It is not clear, of course, that actors will form coalitions purely on the basis of shared perceptions of causal linkages between goals. For example, if two actors perceive the same negative linkage between two goals, they may take opposite positions on both goals because their underlying interests are opposed. Both oil companies and fishermen may see offshore oil exploitation as incompatible with fishing, but the oil companies will favor exploitation over fishing, and the fishermen will oppose oil exploitation. Thus shared perceptions may actually enhance the likelihood of conflict if a real conflict of interests exists.

One fact that can be derived from Table 8–2 is that the ocean debate is not unidimensional. There are several goals, for which actors tend to divide into opposing groups in different ways. For example, on the issue of innocent passage, it is the oil exporters and the Other LDCs versus all others. On the other hand, on oil exploitation the oil exporters join with the developed nations in favor of offshore oil, with only the Other LDCs opposed. On fishery conservation, the Other LDCs share the Soviet Union's view that conservation is undesirable. There are, therefore, opportunities for the creation of issue-specific alliances between developed and developing nations. The total pattern of alignments could be cross-cutting and nonpolarized.

Possible Determinants of Support for an Ocean Regime

Analysis of the data and definitions for comparative measures of the separate actors' goal structures provide the preface for a more detailed analysis of the primary concern, establishment of an international ocean regime. In that regard, the present considerations will include a presentation of separate actors' views toward the establishment of an ocean regime. Table 8–15 presents: the position of each actor on the establishment of such a regime; the salience of this goal for each actor; the distance of the goal structure of each actor from that of the judges; and the structural influence of the regime.

TABLE 8–15

RELATION BETWEEN POSITION TOWARD INTERNATIONAL OCEAN REGIME AND OTHER STRUCTURAL MEASURES FOR EACH ACTOR

	U.S.	*USSR*	*OECD*	*Oil ex-porters*	*Other LCDs*	*Oil in-dustry*
Position [a]	+	—	a	o	+	—
Salience [a]	med	low	med	low	high	high
Distance from judges [b]	69	76	71	124	95	128
Symmetry [c]	.95	.72	1.06	.44	1.06	.86
Structural influence [d]	.01	.03	—.02	—.01	.01	.05

[a] See Table 8–2.
[b] Distance of goal structure from the estimates of the group of judges: see Table 8–13.
[c] The number of positive and negative linkages between pairs of goals divided by the number of positive-nil and negative-nil asymmetric linkages.
[d] In computing this measure for the ocean regime goal, I considered all non-nil linkages to be the same. Thus, all signs were ignored. See text for an explanation of the structural influence measure.

As Table 8–15 illustrates, the United States supported the goal of establishing an ocean regime with a moderate saliency, while the other LDCs were supportive of the issue, which had high saliency for them. The OECD states demonstrated ambiguous feelings and moderate salience, while oil exporters had no opinion. The major opponents to a regime are the oil industry, the Soviet Union, and some OECD states. Can opposition or indifference

to an international ocean regime be explained in terms of other characteristics of the goal structure than its density or balance?

Table 8–15 shows that opposition to an international ocean regime is associated with the perception of asymmetric linkages, distance from the judges' goal structure, and a high estimate of the causal independence of the ocean regime. The two actors with the greatest distance from the judges' goal structure, the oil exporters and the oil industry, actively oppose or do not favor the regime. The three lowest scores on a symmetry index correspond to the three actors who least favor an international regime. The two main opponents of the regime, the oil industry and the Soviet Union, are also the actors that give the regime the highest scores in terms of "structural influence." The measure of structural influence is an indicator of the ability of a specific goal variable, in this case the international ocean regime, to affect other goal variables, both directly and indirectly, without being affected by them (Taylor 1969). Thus, even though the ocean regime affects many of the other goal variables for the United States, the structural influence of the regime is low because it is affected by a large number of the other variables.

Having completed this detailed analysis of the cognitive maps, I would now like to describe what took place at the Caracas Conference on the Law of the Sea. This description will aid in evaluating of the cognitive map technique as a way of understanding the ocean debates.

WHAT HAPPENED IN CARACAS?

More than 5,000 delegates and observers from 148 nations attended the Caracas Conference.[9] Although there was some dispute over the failure to invite the Vietcong and Taiwanese representatives, the delegates soon got down to the business at hand. The range of issues discussed closely resembled those listed in Table 8–1, with a few important exceptions. Limiting the expansion of national jurisdictions was divided into two subissues: (1) setting a limit on the width of the "territorial sea"; and (2) setting a limit

[9] This description of the Caracas Conference is based on journalistic accounts in the following sources: *New York Times*, June 21, 1974, p. 12; July 2, 1974, p. 8. *The Times* (London), August 19, 1974, p. 5; August 20, 1974, p. 4; August 25, 1974, p. 3. *The Economist*, June 22, 1974, pp. 28–30; July 20, 1974, pp. 39–40.

on the width of a wider "economic zone." Most versions of this compromise called for national control over fishing and mineral exploitation in the economic zone and over navigation and scientific research in the territorial sea. However, Canada, Iceland and most of the developing nations favored extending national control over pollution and scientific research to the economic zone. Most nations came to the conference willing to settle for a 12-mile territorial sea and a 200-mile economic zone, with the notable exceptions of Japan and the Soviet Union. This created new difficulties, since the wider territorial sea meant that certain straits, including the Straits of Gibraltar and Malacca, which had previously been open to all navigation, could theoretically be closed by coastal states. The United States, Britain, and the Soviet Union therefore called for "unimpeded passage through straits." Unlike innocent passage, unimpeded passage does not require submarines to navigate on the surface and to show their flag when passing through another nation's territorial sea. This surfacing procedure would make it impossible for the superpowers to conceal the movement of their submarine fleets.

The nature of the regime (or regimes) that would be responsible for the regulation or exploitation of the international part of the oceans (the area beyond the economic zones) was a matter of considerable disagreement, both before and after the conference. A number of developing nations, including the People's Republic of China, favored a strong authority which, by entering into joint ventures, would itself develop ocean resources for the benefit of all nations. The United States and the European Community nations wanted the authority to be limited to the licensing of private or public enterprises, with the licensing revenues to be distributed to all nations.

Formation of coalitions was not as marked as one might have expected from the analysis above. Although there was clearly a split between major powers and developing nations on the issue of national control over the economic zone and passage through straits, that debate and the debate over the international regime saw divisions within both groups. For example, the British and the Soviets were opposed to even a limited licensing authority, while the developing nations with onshore mineral resources were opposed to a strong regime because of the expected effect on world prices. Canada and Iceland took strong stands in favor of the control of pollution in the economic zone. Lobbying by commercial interests was extensive both before and during the conference. Nevertheless, the oil industry and the oil-exporting nations played a much smaller role than expected in the debate because of the initial consensus on the expansion of national jurisdictions. A strong division between the landlocked countries and others did not materialise. The thirty-one landlocked nations tied their hopes to the proposal for a strong international regime, effectively allying themselves with the developing nations.

The next session of the conference will probably focus on a compromise in which a stronger international regime is traded for guarantees of free passage through straits and outside the territorial sea. The number of alternatives on other issues was considerably decreased in the Caracas meeting, so the agenda will be less filled with items for discussion.

Also, the Caracas meeting agreed on a voting formula by which the required majority will be two-thirds of those voting yes or no, so long as those voting yes include at least half of the participants. So the outlook for the successful conclusion of an agreement on a new law of the sea is good, as long as there is a chance of resolving the issues of: (1) the distinction between the territorial sea and the economic zone; (2) unimpeded passage through straits; and (3) the nature of the regime for the exploitation of the international part of the oceans.

SUMMARY OF RESULTS AND EVALUATION OF THE COGNITIVE MAP TECHNIQUES

Given the events in Caracas as described above, it becomes possible to say something about the utility of the technique. Some vital elements of the debate were reflected in the estimation of cognitive maps. Actors did tend to rationalize their positions on the basis of connections between issues. A good example is the issue of economic zones that include national control over pollution and scientific research. Nations favored such control, not because of their irrational nationalistic tendencies, but primarily because they believed such control necessary for the management of coastal fisheries or the regulation of offshore oil exploitation. Nations that opposed this control were concerned that strict pollution control might limit the access of merchant and military fleets to the economic zones.

Several rather important shortcomings of the analysis were evident, however. First, and probably most important, the study did not take into account the variety of *types* of regimes that would be under discussion. The group of judges looked at a regime that resembled the most ambitious proposal put before the Caracas Conference. A separate analysis for each type of regime proposed would have been desirable, and certainly would have improved the descriptive and explanatory value of the exercise. Second, the issues changed over time in ways that were not foreseen. For example, the research group did not foresee the division of national jurisdictions into territorial seas and economic zones. They did not foresee the development of the idea of unimpeded passage as an alternative to innocent passage. Third, some issues, like the alleviation of world protein deficiences, did not obtain the prominence that was expected.

In the absence of a detailed description of the Caracas Conference in terms of cognitive maps, it is impossible to evaluate systematically the technique's descriptive accuracy. Nevertheless, it clearly failed to take into account changes in the issues, and perhaps the beliefs of the participants. However, it did yield several hypotheses or conjectures about cognition that may be of general interest: (1) positions of actors may be inconsistent with causal beliefs about linkages between goals when the actor is a nation-state, because of domestic pressures, bargaining behavior, compromises within the government, and the differential ability of individuals to tolerate ambiguity; (2) actors with similar positions tend to have similar beliefs; (3) actors tend to perceive more linkages between highly salient goals than between less salient ones; and (4) in a situation of high complexity and ambiguity, actors may favor a policy that they perceive to have low causal independence more than one that promises to have a direct effect on several issues without being subject to feedbacks.

These hypotheses, if backed by further empirical study, could help to improve the utility of the technique as an explanatory and predictive, as well as descriptive, device. That is, one could begin to explain *why* nations take the positions they do or *why* they choose specific coalition partners in terms of cognitive maps. This would make it possible to suggest ways in which positions or alignments may be changed by the judicious mustering of facts and evidence about the linkages between goals. If, for example, it is true that actors with highly connected maps prefer policies with low causal independence, and if one would like to see a particular

policy implemented, then one would presumably want to encourage the view that the policy will be subject to a lot of feedbacks. Similarly, if one is merely interested in obtaining agreement or consensus among a group of actors, one should encourage the actors to harmonize their beliefs about causal linkages. Finally, one could change the position of some actors by manipulating the salience of issues. These are procedures that would probably not occur to anyone without exposure to the use of cognitive maps. It is precisely this potential for generating accurate descriptions, rational explanations, and new (and even counterintuitive) propositions about persuasion and consensus-building in situations with actors of highly divergent political perspectives that recommends the cognitive mapping technique for further study.

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