

TOTALITY INDEXES FOR EVALUATING ENVIRONMENTAL IMPACTS OF HIGHWAY ALTERNATIVES

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The passage of the National Environmental Policy Act of 1969, general tightening of pollution laws, and increasing public concern for environmental quality make it mandatory that environmental impact studies be done for proposed construction of facilities such as major highways, airports, dams, and atomic power plants. So that the long-range impact of specific or alternative developments can be appraised, principles of environmental and systems sciences are being applied to the scaling and weighting of the factors. Increasingly, government is turning to academic centers for help and research on environmental impact studies. This paper is a brief account of how, by use of a simple linear vector analysis as an objective quantification of environmental impact, an organized interdisciplinary group at the University of Georgia responded to a specific request from the Georgia Department of Transportation. The paper also discusses how this was followed by a sequence of events that have profoundly influenced and improved the entire transportation process in the Southeast.

•IN the spring of 1971, the Georgia Department of Transportation requested that the Institute of Ecology at the University of Georgia make a summary evaluation of all reports already prepared on alternative routes for the uncompleted section of I-75 north of Atlanta. Previously, the original route proposed by the Georgia Department of Transportation (route F, Figure 1) had not been approved by the Federal Highway Administration because of objections by environmentalists who pointed out that the route might degrade a prime greenbelt and recreational area of great importance to the future of metropolitan Atlanta.

Accordingly, the Georgia Department of Transportation surveyed several alternate routes, both to the east and west (routes T, G, P, and O, Figure 1), and prepared reports on engineering feasibility and costs and benefits for all the routes. State, federal, and citizens' organizations and two private consulting firms were requested to submit reports. The reports submitted included the special interests of the Georgia Department of Transportation; U.S. Army Corps of Engineers; Georgia Department of Mines; U.S. Bureau of Mines; Georgia Department of Public Health; U.S. Geological Survey; U.S. Environmental Protection Agency; National Recreation and Parks Association; Georgia Recreation Commission; Bureau of Outdoor Recreation, U.S. Department of the Interior; Natural Areas Council of the State of Georgia; Georgia Department of State Parks; the Georgia Game and Fish Commission; and the U.S. Fish and Wildlife Service. Bolt Beranek and Newman, Inc., submitted an acoustical impact study. We at the University of Georgia agreed to evaluate the data from these reports, not only

Figure 1. Five proposed alternatives for I-75 north of Atlanta.

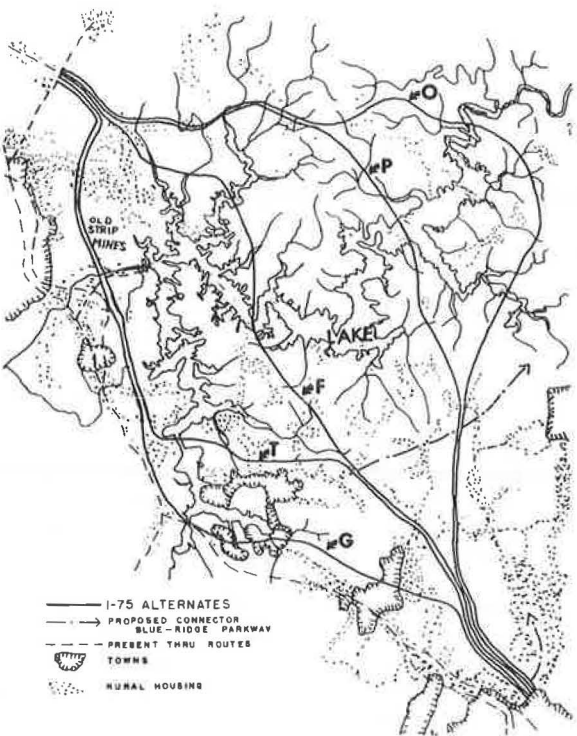
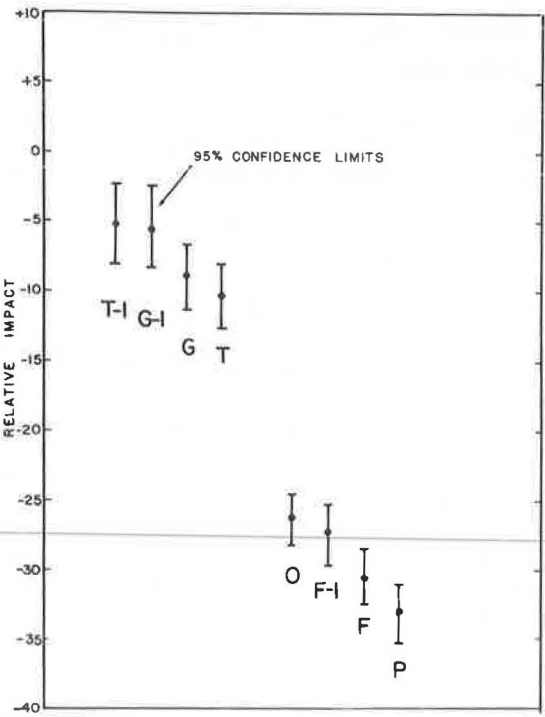


Figure 2. Mean and 95 percent confidence interval for total impact index of eight routes proposed for uncompleted section of I-75 north of Atlanta.



because we thought we might help resolve a classical confrontation between engineers and environmentalists, but, more important, because we thought we could develop a systems-ecology procedure that might have wide application to other situations where protection of the future quality of the environment is paramount and where decision making is to be based on selecting the best among alternative sites or procedures. Accordingly, our objective was to make a summary evaluation of each proposed route in terms of a single impact index, compounded by quantifying, weighting, and scaling all component values for which data or expert opinions were available. In carrying out the evaluation, we functioned as an ad hoc interdisciplinary panel with a 50-50 balance between those accustomed to dealing with environmental matters and those skilled in the application of economic and human considerations.

METHODS

When the project was first considered, several ways to accomplish the objective were examined. One possibility was what might be called the McHarg method (1), which involves preparing transparent map overlays of the area under consideration with a gradient of classes of density varying with land use or other considerations, such as human population density and slope of the land. When many overlays are superimposed on the basic map, a route of least harm or least resistance may show up as the lightest zone area. Such a graphic method may often provide a means for selecting a single alternate route or location but is rarely sensitive enough to decide among alternatives already selected and studied on the basis of engineering feasibility. The use of matrices for problems of this sort has been suggested by Leopold, Clarke, Hanshaw, and Balsley (2), and matrices have been applied in an actual situation in Wisconsin (3). Considering that we did not gather the data and that we would be dealing with information and value judgments from a wide variety of sources, a relatively straightforward linear vector analysis appeared to be the best approach for the problem at hand.

The method decided on was essentially a linear combination of observable or consensus attributes (e.g., the amount of urban land disturbed, the relative safety of a route, the cost of a route) multiplied by a weighting factor giving the relative importance of the particular attribute. For each alternative route, an impact index I was evaluated from these weighted attributes. A mean impact index \bar{I}_k and a standard deviation σ_k were determined by iteration of the impact index I for respective routes k . The parameters (mean \bar{I}_k and standard deviation σ_k) were then used to infer impact differences among various routes. The definition of the index I is as follows:

$$I_{kj} = \sum_i (e_{kji} + 1/2) N_i S_i X_{ki} \quad \begin{array}{l} (i = 1, \dots, 56 \text{ attributes}) \\ j = 1, \dots, 20 \text{ iterations} \\ k = 1, \dots, 8 \text{ routes} \end{array} \quad (1)$$

where I_{kj} is the j th iteration of the impact index I for the k th route; X_{ki} is the response of the i th observable or consensus attribute for the k th route;

$$S_i = 1/\text{Max} [X_{ki}; k = 1, \dots, 8] \quad (2)$$

is a scaling factor on the i th observable attribute; and $0 \leq S_i X_{ki} \leq 1$ will be true for every attribute on every route.

$N_i = W_i / \sum W_i$ is a scaling factor on the i th observable attribute such that $\sum_i N_i = 1$ (this scale factor is derived from the unscaled importance weights W_i assigned to the i th observable attributes).

e_{kji} is a random number drawn from a uniform distribution for the i th attribute on the j th iteration of the index I of the k th route. This random number will vary between 0 and 1. The scaled random number $(e_{kji} + 1/2)$ will then permit the attributes to vary by 50 percent.

The 56 observable or consensus attributes that make up the final data set are loosely categorized into four groups:

1. Group E, economic and highway engineering considerations;
2. Group L, environmental and land use considerations;
3. Group R, recreation considerations; and
4. Group S, social and human considerations.

A complete list of the 56 observable attributes, their weights as assigned by the panel, and the source of the data are given in the appendixes of the final report (4). The procedure for scaling and weighting attributes is described below.

To convert the many different observable responses expressed in different units [such as costs measured in dollars, safety measured in human lives saved, watershed erosion measured in tons (kilograms) of soil disturbed] into comparable units, we set the route with the maximum value for the attribute at unity and scaled the remaining routes relative to this standard. The 0 to 1 scale was chosen simply for ease of calculation and comprehension; any other ranges could be arbitrarily set (i.e., 0 to 10, 0 to 100). A scaling factor, as previously cited, then has the form of equation 2. For example, for acres (hectometers²) of urban area disturbed for the different routes (attribute 9), some route responses are $G = 212$, $T = 175$, $F = 68$. Of these responses, line G at 212 is the maximum value.

Therefore,

$$S_{\text{attribute 9}} = \frac{1}{212} \quad (3)$$

Next the i th attribute on the k th route is multiplied by the i th scaling factor so that

$$G = \frac{212}{212} = 1 \quad (4)$$

$$T = \frac{175}{212} = 0.825 \quad (5)$$

and

$$F = \frac{68}{212} = 0.321 \quad (6)$$

This process makes the i th attribute for each route a dimensionless number that can be used to indicate the relative merit of each route.

Since attributes in an analysis of this sort are not of equal importance in terms of the overall impact, some systematic method of weighting their response must be devised. Again, an arbitrary range was selected, this time 1 to 10, and both present and long-term weights were used, although the latter were emphasized since the major controversy (hence the major problem the study was set up to resolve) involved questions of future impact on large greenbelt recreational tracts and small towns north of Atlanta.

It was decided that the importance of long-range effects should be 10 times greater than that of present effects. Because of storage limitations on the computer these were combined into one importance weight. For example, for attribute 1 [acres (hectometers²) of pineland removed] the future effect was -10. The importance weight actually entered was

$$\text{importance weight of attribute 1} = 1 (-3) + 10 (-10) = -103 \quad (7)$$

The minus signs in equation 7 indicate that removal of the existing pine forests is an undesirable or detrimental effect. The increased negative impact for the future is based on the fact that the future commercial development that inevitably follows major highway construction will remove more forest than was removed in the right-of-way construction of the highway. In another example, urban acreage removed (attribute 9), the value entered was

$$\text{importance weight of attribute 9} = 1 (-6) + 10 (+10) = +94 \quad (8)$$

Change in sign for future effect in equation 8 was based on the projection that, although displacement of homes and businesses in the right-of-way would be a detrimental factor at first, the long-range impact would be favorable to an underdeveloped urban area since the highway would bring increased economic benefits to the community as a whole.

The importance weights of the attributes were normalized to keep results within reasonable and understandable bounds. This procedure involved simply dividing each weight by the total sum of all weights, as shown by the previous notation, ΣW_{1-56} . In this way a central point of tendency of the weights is established rather than a variety of weights from 0 to infinity. In no way are the relative positions or spreads of the final index values for the routes modified; only their absolute positions on a scale are changed.

A computer program to calculate indexes for each route and to iterate the index of the route, given the variability of each of the values, was written for this study. Details of the program, written in CPS PL/1, are contained in the full report (4). It takes up to 60 values; iterates the index 20 times; and produces the mean \bar{I}_k , standard deviation σ_k , and a 95 percent confidence interval for the index I . A pass using 50 values requires about 3.5 min of CPU time on an IBM 360/65. Program notation refers to k_i , which are importance weighting factors W_i , and to d_i , which are scaled attribute responses ($S_i X_{ki}$). The weighting factors b_i are set internal or external to the program, but the scaled responses d_i are set external to the program.

The major problem in evaluating environmental and socioeconomic values associated with highways is that subjective judgments are often required. Experts often disagree about the importance of different values and their impact, and this disagreement complicates the assessment of ecological costs and benefits.

In this study, we relied on expert opinion and value calculations as recorded in the series of reports by specialists and on the consensus of our panel that established the weighting factors. Most of all, however, imprecision was allowed for by assuming that changing attribute responses, opinions, or weights might vary by 50 percent. This is the $e_{k,j}$ factor in the index formula I_{kj} or as detailed previously. For the current study, all attributes were assumed to vary with the same amount of variability, namely 50 percent. This was an adequate assumption since no prior knowledge was available regarding variability of these attributes. Future studies that have access to the amount of variation possible in attributes should permit the error probability to vary for each attribute.

By using randomly varying values to determine the index several times, one can determine an average index \bar{I}_k for the route in question and how much this index can be expected to vary. Standard statistical techniques can then be used to find the best

route, given that there is some inexactitude in the values that go into the index. Note that the establishing of a confidence range should be mandatory in any statistical evaluation of impact data, even in strictly economic data that can also have a wide range of error. In this study, $I_{k,j}$ was assumed to be normally distributed. A 95 percent confidence region could then be placed about \bar{X}_k by application of the t-distribution.

The form of the confidence interval is as follows

$$(\bar{I}_k \pm S_{I_k} t_{0.05, 19}) \quad (9)$$

where \bar{I}_k is the mean impact index for route k ; S_{I_k} is the standard error associated with the mean impact index \bar{I}_k ; and t is the proportionality of the t-distribution associated with $\alpha = 0.05$, and $df = 19$.

In summary, the weights selected were those chosen by the study group after much discussion and careful consideration. However, the possibility that any given weight is not properly proportional to other weights is provided for in the error control of the program, as described.

RESULTS

The results of the analysis in terms of the mean and 95 percent confidence interval for each of the alternative routes are shown in Figure 2. The main analysis resulted in a sharp separation of the routes into two groups of four each. The fact that both groups have negative values does not mean that a highway would be detrimental to the areas involved because these are relative, not absolute, values. A value close to zero merely indicates a relatively neutral or favorable impact in terms of a balance between economic and environmental factors, and values of -30 indicate a much less desirable choice, all things considered. The mean values (as shown in Figure 2) for the eight routes, in order of the ranking from best to poorest by the main stochastic run, are as follows:

<u>Route</u>	<u>Ranking</u>
T-1	-5.2
G-1	-5.4
G	-8.9
T	-10.3
O	-26.5
F-1	-27.3
F	-30.6
P	-33.2

Figure 2 shows little reason to choose between routes T and G. Route T-1 has a slightly lower mean, but the difference between it and the other three westerly routes is statistically insignificant. The slight advantage of T-1 was related to lesser impact of the family displacement and noise disturbance, all other components being almost identical for the T and G routes.

The remaining four alternatives, including the originally proposed route F, were not so closely bunched, but their mean indexes were significantly lower than for any of the westerly four. This indicates that these easterly routes would be inferior choices.

To determine more clearly the role played by the major groups of component values in the numerical value of the total index, trial runs were made in which one or more of the groups were omitted. When future impact values were left out so that only the immediate impact was considered, the routes ranked as follows:

<u>Route</u>	<u>Ranking</u>
T-1	-31.8
F-1	-32.2
F	-34.6
G-1	-34.8
T	-37.8
G	-39.1
O	-43.5
P	-44.2

Although T-1 was still ranked highest, the negative values were lower, and the T and G routes would not be statistically different from F. The reasons why consideration of the future resulted in much clearer separation of alternates will be discussed in the next section. When environmental factors only were considered (i.e., when strictly economic and human factors were left out and vice versa), the rankings and degree of separation of western from eastern routes differed little from the total run. This indicated that there was no undue bias toward either environment or man in the total run. Finally, a trial run was made to determine the effect of a higher weighting for safety, since one of the objections of the longer routes would be that the extra length might result in more lives lost in accidents. Increasing the relative weight of the safety factor did not reduce the superiority of the T and G routes over the shorter F route. As it turned out, the hazard of 3 extra miles (4.8 km) was more than balanced by the hazards posed by two long bridges that would have to be built across the lake on route F. Likewise, the cost of extra paving and higher land acquisition values along the T-1 route turned out to be less than the cost of these bridges. These various experimental manipulations illustrate both the use of the computer model as a tool and the kind of detailed analysis that can be made even with a simple linear program.

On the basis of the complete study, it was recommended that one of the T or G routes, preferably T-1, be selected. The Georgia Department of Transportation accepted this recommendation and proceeded with public hearings and additional engineering plans for route T-1. Engineers with the regional office of the Federal Highway Commission became interested in our study and joined with us to rerun the program with some changes in the weighting of factors they considered important. These new runs produced the same result, a clear separation of the two groups of routes as shown in Figure 2. As of this writing, the Federal Highway Commission has approved the T-1 route.

DISCUSSION OF RESULTS

In retrospect, two features of this study that seemed to have encouraged acceptance of the results by government, political leaders, and the general public were the strong emphasis (i.e., weighting) given to future impact and the establishment of confidence limits (Figure 2), based on the possibility of a wide margin of error in any one of the 56 component values. Strong weighting of the future resulted in clear separation of alternates because the future impact differed markedly from present impact in a number of important categories. For example, routing the highway parallel to an existing main artery and along the outskirts of existing towns, villages, and suburban areas, such as long routes T or G, results in an immediate negative impact in terms of displacement of people and higher land acquisition costs. However, if we look to the future, people in these preexisting centers will benefit greatly because an Interstate highway is an irresistible magnet for economic development. Furthermore, conditions are favorable for orderly economic development that benefits local people since the incorporated towns and villages either have, or can soon establish, services such as water and sewage systems and land use zoning. Furthermore, old strip mines and other blighted areas along routes T and G would be greatly improved by a well-engineered and well-landscaped double highway with a wide median strip (as is recommended). In

contrast, routing the highway through the recreational wilderness now present along route F would have little immediate impact either on the quality of the wilderness or on people (since few live there). However, in the future, the quality of the natural area would be increasingly degraded by an economic development that would likely be exploitive and speculative and that would benefit large landholders and outside interests rather than local people. Since, in the long run, the quality of urban areas depends on the quality of the buffer life support system (i.e., water, air, fiber, and food in the environment), it makes common as well as economic sense not to route major highways through such greenbelts needed for future use by large metropolitan centers such as Atlanta. It was not until all the individual factors had been carefully and objectively weighted, scaled, and incorporated into a totality program that this kind of logic became evident.

As already indicated, the computer program was set to assume that there might be 50 percent error in any value. Although it seems highly unlikely that data and expert opinions would be doubted, it is prudent to start with a large error factor. In this case, a clear separation was obtained even with the large error factor. Therefore, it was not necessary to consider reducing the error estimate to reach a decision.

Although a linear vector approach proved to be adequate for this study, some form of matrix analysis (2, 3) would undoubtedly provide greater flexibility and sensitivity in cases where component values for the options prove not to be so divergent. However, the usefulness of more complex procedures depends greatly on the quality and comparability of the data; far better impact reports than many of those made available for this study would be needed. We would strongly recommend that special training courses in computerized impact analysis be set up at academic centers designed especially for personnel of state, federal, and private consultant agencies who will be increasingly called on to make decisions that are in the best long-term public interest.

The ultimate success of a totality approach such as that used in this study may often depend on follow-up procedures. For example, when the highway was rerouted along T and G (Figure 1) as recommended, a superb opportunity for land use zoning was presented, since a large recreational greenbelt would then lie in the V between the developing urban corridor (Atlanta to Chattanooga) on the west and the commercial, recreational developments (e.g., resorts, second homes) that are springing up along the Blue Ridge Parkway extension to the east. Thus, Georgia has an opportunity to set aside all of the area around and north of Lake Allatoona as a permanent greenbelt for metropolitan Atlanta. This could be done by expanding the state parks already located in the area or by acquiring easement rights from large landowners (chiefly timber companies) to ensure permanent natural areas for public use. If these follow-up actions are not taken now, there will inevitably be pressure in the future to extend highways and urban development northward, thus splitting up and ultimately destroying a valuable natural resource that was saved, so to speak, by the earlier decision to locate I-75 to the west.

Shortly after the results of this study and the decision on it by Georgia DOT were made known to the public, an editorial cartoon appeared on one of the Atlanta TV programs (5) depicting economics (in the form of a coin purse) and ecology (in the form of wildlife) dancing together over the caption, "We both won by the decision to reroute I-75."

CONCLUSIONS

Our experience with this and similar studies leads us to think that, although short-term economic considerations (especially when exploitive and speculative) usually result in environmental degradation, long-term cost-benefit analyses (in which all costs are considered) will generally be beneficial to the environment. In other words, what is good for the environment will also be good for a long-term stable economy. It would be hard to fault such a concept as a goal for the upcoming generation who must make what Boulding (5) calls the "great transition" in the country's economic and ecologic game plans.

The decision to reroute I-75 has been followed by a series of events in Georgia that we think are indicative of a transition to a new era of planning that involves not only greater consideration of the environment but also greater citizen participation in the planning process. Brief mention of these transportation decisions will show how attitudes have changed from the days when road building was strictly a matter of power politics.

The Institute of Ecology was also asked to evaluate alternate methods of handling the muck that has to be removed when highways are built across wetlands. Based on the recommendation of this study, procedures in the construction of I-95 on the Georgia coast were modified to minimize damage to valuable coastal marshes. In another case, Georgia voluntarily altered the route of an Interstate connector to avoid cutting through a scenic ridge with unusual flora; in this case, the decision came 2 days before a scheduled hearing was held on a court suit based on the contention that an impact study such as that done for I-75 had not been carried out for alternate routes.

Finally, in the fall of 1972 the governor of Georgia appointed an ad hoc study commission of knowledgeable citizens to determine whether an outlying freeway should, or should not, be extended as a tollway to downtown Atlanta. The commission used our vector approach in that about 30 value components were established, and each member of the commission personally weighted the values. In this case computer analysis was not necessary because members of the commission came to the same conclusion when making a total analysis although they differed greatly in the importance given to some of the values (commission members included business and professional leaders, planners, a chamber of commerce official, an environmentalist, and a spokesman for the neighborhood directly affected by the proposed highway). The preservation of inner-city neighborhoods, the strong public opinion against the road, and the fact that plans for rapid transit and improved bus service offered transportation alternatives all weighed heavily in the unanimous decision to recommend that the tollway not be built. On the same day that the commission made its report, the governor and the director of the transportation department announced that the tollway would not be built.

The most encouraging feature of these events is the strong indication that an orderly means of structuring citizen involvement in complex planning problems is about to evolve. Fielding (6), a social scientist, used the term value analysis for this emerging strategy, which he says

... differs from cost-benefit and goal-matrix methods in that it does not presume in advance that a social welfare function for a freeway exists. Instead it assumes that an attitude is developed during the planning process. Value analysis assists diffusion of reliable information about freeway proposals and develops a behavioral commitment for the decision within the affected community.

The kind of systems ecology described in this paper may yet provide a technological assessment link between science and society.

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APPENDIX

ANATOMY OF IMPACT ASSESSMENT

During the past 2 years, numerous conferences and workshops have been held all over the country for the purpose of developing some kind of state of the art for preparing environmental impact statements, as required by the National Environmental Policy Act of 1969. At one such workshop conference, scientists and engineers primarily interested in the practice of impact assessment examined in detail the matrix approach (2), the linear vector approach described in this paper, and other proposed approaches. On the basis of this workshop, E. P. Odum prepared the following outline of how to assess various environmental impacts.

The Component Approach (Linear Vector or Matrix)

1. Make a list of the components or values (the inventory data base).
2. Scale component values and indicate whether they are positive or negative to permit summation.

Stop 1.

3. Weight each component value (multiply by factor proportional to importance). Give specially sensitive components (red flags) extra weighting.
4. Sum scaled and weighted values to obtain impact index.

Stop 2.

5. Introduce error factors by computer program.
6. Do a sensitivity analysis (experiment by computer program with changed weights, errors; leave out or add components judged to be of key importance or of much public interest).

Stop 3.

7. Add additional weights for future or secondary impact where importance values change with time. Try nonlinear functions (as in Battelle approach).

Stop 4.

If interactions and forcing functions are more important than components or if scale of problem is large and complex or if the ultimate decision does not involve a simple choice of alternates (i.e., A, B, C; go-no go), then go to the next approach.

The Systems Approach

1. Make a list of the properties (state variables) that relate to the function of system as a whole (for example, in an aquatic system, the rate of production as a system property rather than dissolved oxygen as a component).
2. Make a list of causal or forcing functions, such as energy sources and investment money.
3. Construct a flow diagram or model by connecting properties (shown as boxes) and forces (circles) with flow lines and appropriate interaction functions (shown as triangles or other distinctive symbols).
4. Indicate where interactions are multiplicative, threshold, feedback, or otherwise not simply additive.

5. Quantify (put numbers on) each major function.
6. Validate the procedure. Run simulations with an analog computer to adjust network behavior to achieve reasonable mimic of real-world system.
7. Do a sensitivity analysis, if needed.
8. Generate performance curves to predict effect of development options, pollution perturbations, or whatever impacts are relevant.
9. If greater detail or precision is required, program with a digital or hybrid computer.

One goes only as far as needed to achieve the goal. Impact statements for many situations need go only to stop 1 or 2. Linear vector analysis through stop 4, as described in this paper, would seem adequate for most situations where there are clear-cut options or alternatives. The procedure is easy to follow and easily explained to the public. This is important since all workshop participants agreed that the public must now be continuously involved in the decision-making process. For more extensive or complex situations, one must shift as far as possible to a true systems analysis where the behavior of the whole rather than of the parts is stressed.

We can begin to see that the present practice of making impact assessments for each and every proposed development, as now required by the National Environmental Policy Act of 1969, is a stop-gap approach that must evolve as rapidly as possible into regional land use planning. Practical success in such an endeavor will require a whole new order of yet-to-be-developed systems procedures, changes in public attitudes, laws, and economic incentives. To meet this challenge, researchers in the sciences and humanities must find a common language and work together. This may involve use of energy as a common denominator in the assessment of the impact of fuel-powered systems on natural, solar-powered systems at the regional level. Energy can also serve as a common language for economic and ecological considerations, thus extending cost-benefit, trade-off, or balance-sheet analyses to include the nature and work of people (7, 8).

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