MULTIDISCIPLINARY, DESIGN-INTERACTIVE EVALUATION OF LARGE-SCALE PROJECTS

by

George L. Peterson, Associate Professor
Joseph L. Schofer, Professor
Robert S. Gemmell, Associate Professor

Civil Engineering Department, Northwestern University
Evanston, Illinois

Abstract

At the present time, considerable emphasis is being placed on evaluation of the impacts of large-scale environmental design projects. But the state-of-the-art is immature, especially with regard to a structured framework of theory and method. This paper presents and demonstrates improvements based upon the beginnings of a generalized impact model that has evolved through a series of encounters with real-world projects. It goes far beyond the usual checklist of environmental parameters, and considers social and human impacts as well. The method has several key features that are explained in depth: design interaction, identification and partitioning of key variables, a network model of impact channels, multidisciplinary cooperation among diverse specialists, ability to perform with inadequate or uneven state-of-the-art, and educational or catalytic gaming. In the paper, the evaluation method and its theoretical foundations are developed and explained in depth. The method is illustrated briefly by means of an actual case study.

Introduction. Increasing public concern for maintaining and improving the quality of the environment during the past decade has brought about significant changes in the ways in which man-made systems are planned (CEQ, 102 Monitor, Aug. 1973; Manheim, et al, 1971; Highway Research Board, 1969; Thomas, et al, 1970). Stronger efforts have been made to consider the concomitant impacts, or side effects, of such projects, along with the planned effects for which such facilities are designed. Federal agencies have been given the mandate, through the 1969 National Environmental Policy Act, to strive to use such projects and programs to improve, as well as merely to protect, the total living environment (NEPA, 1969).

The revised guidelines for implementing this act, issued by the Council on Environmental Quality in 1973, make clear what kinds of impacts must be considered, and the procedures to be followed in the administrative aspects of the assessment program (CEQ, Federal Register, Aug. 1973).

When the 1969 NEPA requirement for impact assessment was implemented, the absence of a strong methodological base made it difficult to prepare impact statements, and even harder to evaluate them in decision-making processes. Since that time, over five thousand impact statements have been written (CEQ, 102 Monitor, Dec. 1973), and their quality has gone up markedly. Still, an examination of recent statements prepared by reputable institutions suggests that significant problems remain to be solved (Pearson, 1973; UMTA, EIS-GA-73-0588F and EIS-NY-03-0035, 1973).

Perhaps the most serious limitation is the tendency for impact assessment processes to focus on the simple prediction of separate impacts, rather than considering the overall impact process. This leads to a fragmented view which may depart significantly from reality. Furthermore, most predictive efforts of this type deal primarily with intermediate effects, such as levels of environmental pollution, the number of people and jobs to be relocated, and the first-order effects of projects on flora and fauna. The "values" of these separate impacts cannot be determined in the abstract, since each is related to the others, and to the social policy context in which it arises.

Yet, the ultimate impacts may well be measured in undefined social, economic or aesthetic dimensions, and may not obtain for many years; when they do occur, they are likely to be far removed from the simple, first-order changes which resulted from the project under consideration. The revised NEPA guidelines require consideration of second-order effects of projects, although no mention is made of how this is to be accomplished (CEQ, Fed. Reg., Aug. 1973). It should be evident, however, that the real concern may be with the "nth"-order effects. These are difficult to define, and their prediction may be beyond the state-of-the-art (Isard et al, 1972).

It is the premise of this paper that impact assessment should be founded on a rational model of the impact process which reflects the chain of relationships between the technological intervention itself, first-order impacts, second-order impacts, etc. The absence of such a model will lead to fragmented, narrow approaches to impact evaluation which are not sufficiently comprehensive to meet the needs, and which may be more dangerous than no impact evaluation at all.

Another problem of current impact assessment methods is that they tend to be "add-on" activities that occur after the planning or design has been done. Effective integration of impact considerations into planning and design has proved to be difficult, yet it is essential if the design process is to be both responsive and efficient.

Also, excessive complexity in application and interpretation of contemporary impact assessment methods limits the ability of informed citizens to participate effectively in decision making, although participation is required by the 1973 CEQ guidelines (CEQ, Fed. Reg., Aug. 1973). Perhaps even more important, this complexity makes it difficult for decision makers to use the results of such assessments in a meaningful way. To the extent that impact assessment information is not well understood by decision makers, the results will have a limited effect on public policy choices.

This paper describes an impact assessment procedure that is currently in use and under further development by the authors. It has the following desirable characteristics:

1) The method is based on a theoretical model of the processes by which impacts occur;

2) It is design-interactive, in that it can easily be integrated into the design process and offers considerable potential for deductive "backward-seeking" design;

3) It can perform well in the context of an inadequate or uneven state-of-the-art of impact prediction, and allows for inclusion of judgmental estimates of impact;

4) Cooperation of experts from diverse disciplines is facilitated by the framework of the method, which dissects the impacts into many specific questions;

5) Specific disaggregate facts and principles can be examined singly or synthesized into more comprehensive descriptions of impact, including trade-offs among specific parameters;

6) In concept, the method can be generalized to include spatial, social and temporal distribution of impacts;

7) The mathematical structure of the underlying impact model lends itself to a variety of analytical operations which allow the impacts to be explored in depth while also permitting, in concept, powerful mathematical sensitivity analysis;

8) Quantitative descriptions of impacts, either disaggregate or comprehensive, are generated so that alternatives can be compared directly;

9) Real or hypothetical value or policy criteria can be used in the model to evaluate impacts from alternative points of view;

10) Not only does the method express impacts in terms of environmental parameters, it also goes further and translates these into human consequences, thus giving operational meaning to the notion of "social cost";

11) The method is adaptable in concept to a wide variety of environmental design applications, ranging from large-scale public works systems to light, localized interventions in the residential environment; and

12) In addition to quantitative outputs, application of the method comprises an educational and catalytic game that greatly enlightens the participants, modifies the products of planning and design, and stimulates verbal descriptions of impact where the numbers may be inadequate or questionable.

In short, the method explained in the paper responds to many important deficiencies in the state-of-the-art of impact assessment. The theoretical, conceptual framework is described first, followed by a brief description of an application to a regional waste-water management study.

The Generalized Impact Network Model (GINM). It would be a relatively simple matter to describe the impacts of a deliberate change in the built environment if the processes by which the impacts occur were clearly understood. Based on the assumption that they are at least understandable, if not entirely understood, we have developed the notion of a "Generalized Impact Network Model," which we call the "GINM." It is a conceptual framework that has emerged from a series of encounters with real-world problems and dissatisfaction with the state-of-the-art.

The GINM describes the impact process as a network of changes driven by the specific characteristics of the architectural or engineering project in question. The network crosses time, space, people, and things. The links in the network are channels through which changes are transmitted, and the nodes are impact processes that transform input changes received via incoming channels into an output change that is transmitted via an outgoing channel. The impact process is initiated when specific changes (e.g., the attributes of the proposed project) are introduced at various nodes. The impact is assessed by observing the consequent changes at other nodes.

If the network can be set up so that each link is a separately and quantitatively defined variable, then the process at each node can be described by a mathematical equation that relates output to inputs. A hypothetical node and impact process function is illustrated in Figure 1. The output from one such node becomes an input to other nodes, thus generating a network of changes, and the entire network is described by

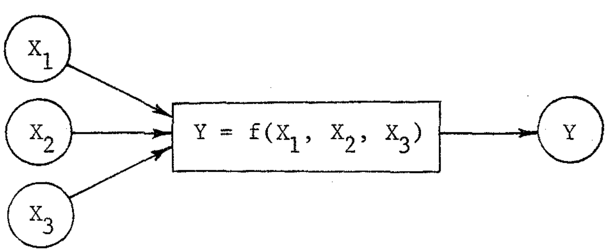

FIGURE 1
Hypothetical Impact Node

a set of equations. When the attributes of a given project are fed into the equations, the impacts can be calculated directly. If there are uncertainties, risks, or ranges associated with any of the variables, sensitivity can also be evaluated mathematically. On the other hand, given a desired set of changes in several of the variables —i.e., goals or objectives —it is conceivable that the equations might be used to specify the required kinds of intervention.

The idea of an impact process function is related to work done at Battelle, Columbus (Dee, et al, 1972), in which an attempt was made to estimate relationships between certain key variables. We extend this general notion into a network of linkages among processes. The closest work found is that of Isard, in which he views impacts in terms of production functions and an economic input-output framework (Isard, et al, 1972). The notion of backward-seeking mathematical approaches to design is related to work done at Northwestern University on regional transportation network design models (Morlok, et al, 1969; Morlok, et al, 1973).

In its ultimate form the GINM would provide a powerful analytical framework for complex system evaluation and design. "All" that is required is complete mathematical specification of the network. Clearly, this is well beyond the state-of-the-art, and is a research undertaking of major proportion. While an operational GINM may not be forthcoming in the near future, we have found, in the meantime, that there are aspects of the approach that have great promise for immediate application to real decision problems. We have been developing and using a simplified version, the most recent application of which was part of a planning study of regional wastewater management systems for the region covering Chicago and the South End of Lake Michigan (C-SELM). This study was conducted by the Chicago District of the U.S. Army Corps of Engineers. This study will be used later in this paper to illustrate the method, but first it is necessary to explain the simplified version of the GINM.

A Simplified Version of the GINM. The simplified model, called GPS, divides the impact process into four stages:

1) Proposed Intervention
2) Environment
3) Society
4) Social Welfare (Policy).

The hypothesis is the following: when attributes or elements of the proposed man-made system are introduced into the environment, they intervene in natural processes, generating products and consuming resources, thereby causing changes in various environmental variables. From the human point of view, these environmental changes are of interest because they, in turn, enhance or impair human activities and states of being. Finally, from a policy point of view, these changes are of varying importance, depending on the values of the individuals and groups affected and their degree of political influence.

Let it be assumed that the system or project to be evaluated can be described as a vector of separate and quantitatively defined attributes or elements:

$$S' = (s_1, s_2, \dots. s_i, \dots. s_m \dots) \qquad (1)$$

where s_i is the magnitude of attribute i; alternatively, if S'is a row vector of discrete elements that are either present or absent in the design, s_i may be a binary variable that takes on the value of "one" when the i^{th} element is present and "zero" otherwise. In later stages of this paper, S is represented as a column vector, as are E and H. For convenience in presentation here, they are shown as row vectors, and the prime symbol (e.g., S') is used to indicate the transposition from a column vector to a row vector, in accordance with standard matrix notation.

Likewise, let changes in the relevant aspects of the environment be described as a vector of separate and quantitatively defined variables,

$$E' = (e_1, e_2, \ldots. e_j, \ldots. e_n) \tag{2}$$

where e_j is the magnitude of change occurring in the j^{th} environmental variable. Finally, let societal impacts be described as a vector of changes in human activities and states of being,

$$H' = (h_1, h_2, \ldots. h_k, \ldots. h_p \ldots) \tag{3}$$

where h_k is the magnitude of change induced in the k^{th} social variable.

The GINM concept suggests that there is a network of impact process functions that relates these variables to each other in such a way that when s_i is introduced into the network, changes occur in e_j and h_k. It is conceivable that S,E, and H can be defined, in some cases at least, so that the major impacts are described within a simple network as shown Figure 2. Should there be interrelationships among the variables in a given stage, feedbacks between stages, or "bypass" effects from S directly into H, these can be accommodated by simply adding more links and more complicated process functions to the network. Assume, however, that Figure 2 is an adequate description of the impact process.

This framework provides conceptual organization for the impact evaluation problem by identifying several key questions or tasks:

1) Identification and definition of the elements of S, E and H;
2) Identification of the impact linkages among the elements and construction of the impact network;
3) Specification of the functional form for each of the nodes; and
4) Estimation of the parameters of each of the process functions.

In some cases, certain of the process functions may be available already in analytical form from previous scientific research. More often, however, they will be unavailable at the scale or in the context required. This presents a formidable obstacle, because each project application may require major investment in original research to specify such functions, and few, if any, project budgets can sustain such expenditures.

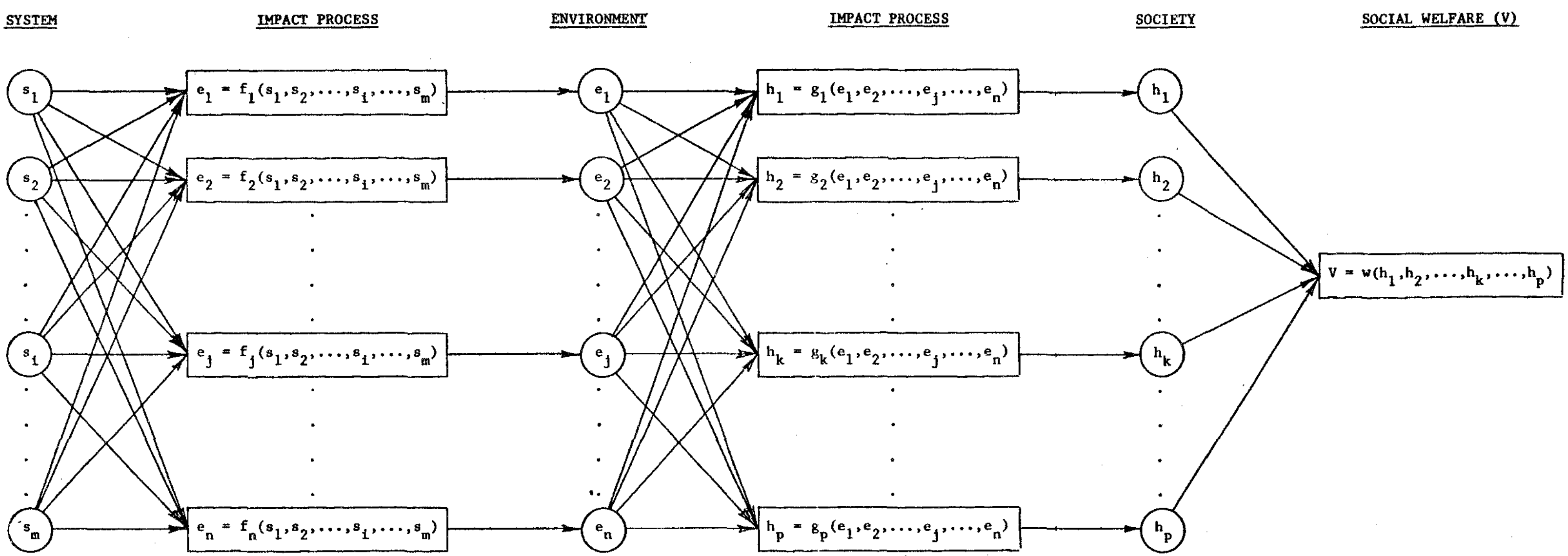

Figure 2

The GSP Version of the GINM

One is thus faced with two alternatives: either this approach to impact evaluation must be abandoned, or an alternative to the conventional analytic method must be found for specifying the process function. Neither legislative mandate nor professional ethics will allow us to abandon responsibility for the consequences of our architectural and engineering projects, so we must find an alternative to scientific rigor until a catalog of suitable phenomenological explanations becomes available.

Although appropriate mathematical process functions may not have emerged from the scientific community, there is still likely to be considerable relevant knowledge available in the minds of experienced individuals. The problem is (1) to identify specific questions to be answered, (2) to identify the person or persons most likely to have knowledge about the phenomena in question, and (3) to develop means for articulating the knowledge in a form that is useful. In the framework of the GINM, the challenge is to convert intuitive or verbal knowledge into quantitative process functions, augmented, perhaps, by verbal elaborations, explanations, etc.

Assuming that questions and people can be properly identified, psychometric methods of measurement can be used to extract quantitative judgments. These methods are well developed. The difficulty is not in the problem of measuring judgment, but in the definition of the thing to be be measured and in finding the person(s) most likely to have the correct information.

In the C-SELM study, the authors applied GPS by first selecting a multidisciplinary panel of experts to serve as judges. The criteria for selection were (1) extensive training and experience in some subset of the spectrum of plausible impact questions, and (2) coverage of the entire spectrum by the panel as a whole. Modified Delphi techniques were used to define the elements of S, E, and H. The alternative systems, of which there were about fifty initially, were described in terms of a set of 26 common design options covering

1) Three treatment technologies
2) Two sludge disposal methods
3) Five degrees of facility centralization
4) Two types of effluent distribution
5) Two options for providing potable water supply, and
6) The option of power generation in connection with one of the treatment technologies.

The environmental and human elements selected by the panel are listed in Tables 1 and 2.

TABLE 1

Environmental Parameters

A. Surface water quality
B. Surface water quantity (temporal and spatial availability, flood prevention or diminution)
C. Subsurface water (groundwater) quality
D. Subsurface water (groundwater) quantity (availability)
E. Air quality
F. Sensory quality of the environment (appearance, noise, odor,etc.)
G. Residential land use (present and potential)
H. Commercial and industrial land use (present and potential)
I. Agricultural land use (present and potential)
J. Recreation and open space land (present and potential)
K. Soil quality
L. Mineral resources
M. Energy
N. Access (transportation, communication, water and wastewater service)
O. Biotic communities (terrestrial and aquatic)
P. Unique or rare things or species

Table 2

Human Elements

A. Commercial production
B. Industrial production
C. Food production (agriculture)
D. Construction
E. Public services (services provided and local expenditures)
F. Private services (services provided and local expenditures)
G. Residential activity
H. Immigration
I. Population density
J. Health and safety
K. Employment
L. Income
M. Cultural/educational activities
N. Public finance
O. Recreation
P. Aesthetics
Q. Ecosystem status
R. Community political structure
S. Community sociological structure

Having thus defined the elements of S, E and H, we might have gone to the panel with the judgmental task of specifying each of the sixteen environmental process functions and each of the nineteen human process functions that are required when the variables are arrayed in the framework of Figure 2. There is no reason why judgment theory cannot be used to specify the functional form. Techniques now in use for "policy-capturing" could be adapted to this task (Rappoport, et al, 1973; Hammond, 1971). However, we chose to simplify the judgment task for purposes of operational efficiency by making some assumptions about functional form.

Let it be assumed that the impact process functions are each separable and linear. For example, this says that the human impact function

$$h_k = g_k(e_1, e_2, \dots. e_j \dots e_n) \qquad (4)$$

can be separated in the following manner:

$$h_k = g_{1k}(e_1) + g_{2k}(e_2) + \dots + g_{jk}(e_j) + g_{nk}(e_n) \dots (5)$$

Assume further that:

$$\frac{dh_k}{de_j} = b_{jk}. \qquad (6)$$

This yields the following impact function:

$$h_k = b_{1k}e_1 + b_{2k}e_2 + \dots\dots + b_{jk}e_j + \dots. + b_{nk}e_n. \qquad (7)$$

In order for this function to be valid, the real world process would have to behave as illustrated in Figure 3.

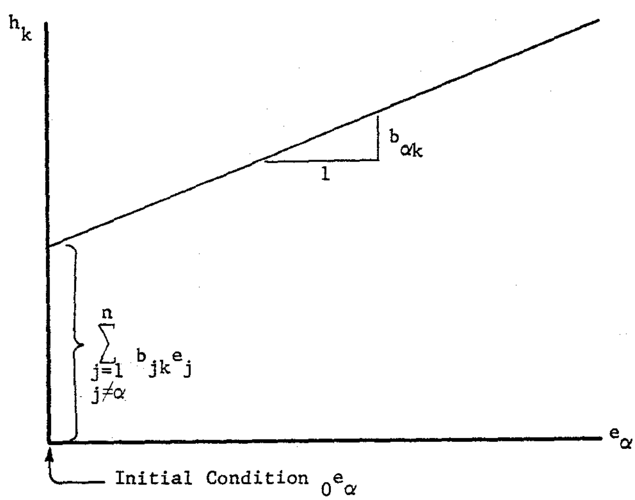

Figure 3

Linear Impact Process Function

If the function is non-linear, as illustrated in Figure 4, and if the linear coefficient is defined as the point slope of the function at some reference condition, the linear approximation will be reasonable for relatively small magnitudes of change. For larger magnitudes of change a linear approximation may still be reasonable if the coefficient is defined as an arc slope in Figure 5 and it is understood as being defined only for a specific system and specific changes.

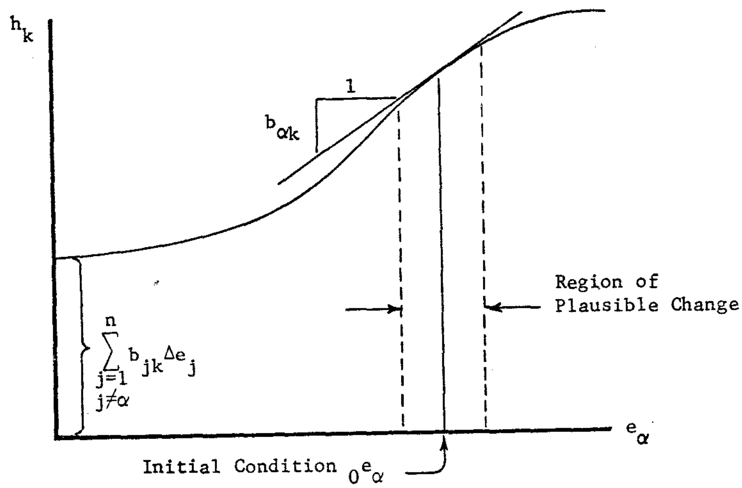

Figure 4

Point-Slope Linear Approximation for

Non-Linear Function with Limited Change

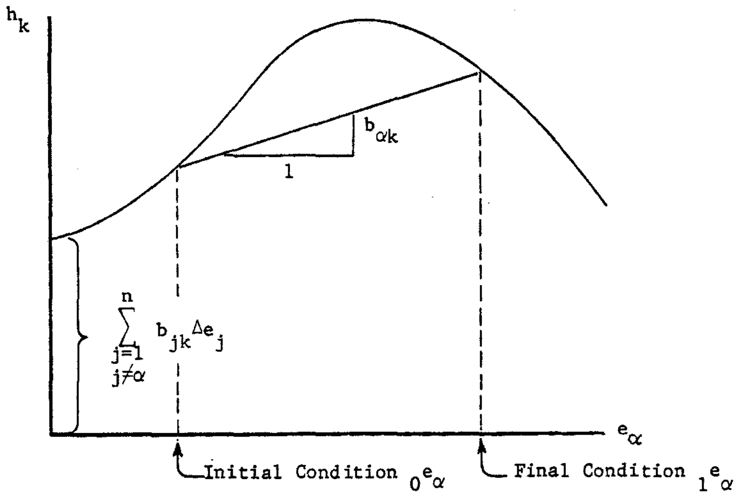

Figure 5

Arc-Slope Linear Approximation for Non-Linear Function with Large Change

These assumptions produce the following mathematical description of the impact network:

$$_qe_j = \sum_{i=1}^{m} (a_{ij}) \, (_qs_i), \tag{8}$$

$$_qh_k = \sum_{j=1}^{n} (b_{jk}) \, (_qe_j), \tag{9}$$

and

$$_qh_k = \sum_{j=1}^{n} (b_{jk}) \sum_{i=1}^{m} (a_{ij}) \, (_qs_i) \tag{10}$$

where
- q designates the design alternative being evaluated,
- i designates the design element
- j designates the environmental parameter
- k designates the human parameter
- a is the linear coefficient for the environmental process function, and
- b is the linear coefficient for the human process function.

In Figure 2, changes in the human variables (h_k) are translated into a social welfare function through a set of policy weights reflecting the relative values or priorities assigned to various human impact dimensions

$$V = w\ (h_1,\ h_2,\ \ldots\ldots\ldots\ldots h_k,\ \ldots . h_p) \qquad (11)$$

In concept this makes sense, but because the political process which establishes these weights is highly implicit, it is generally agreed 1) that this function is difficult and probably impossible to estimate except by observing real political choices after-the-fact, and 2) that the assignment of values is a right of the people through politics, not a technical concern. If a vector of linear weights were available to measure the marginal return, w_k, in social welfare per unit of change in h_k, the welfare unction for the q^{th} design alternative would be

$$V_q = \sum_{k=1}^{r} w_k q_k, \qquad (12)$$

where V_q is the net change in social welfare caused by the q^{th} design alternative.

In the C-SELM study this approach was used to explore the desirability of each proposed system from several hypothetical points of view. The result was analysis of the sensitivity of the decision to alternative value-weightings of the impacts. One way to do this is to measure value-weights for various community groups, using psychometric or Delphi Techniques. These should be regarded, however, as hypothetical weights for the purpose of sensitivity analysis, and not as a prediction of, or substitute for, the political process.

Given the linear formulation of the impact network, the role of quantitative judgment in GPS is simplified to focus on three sets of specific questions:

1. What are the magnitues of the environmental impact coefficients, a_{ij}? (Given the introduction of design element s_j, what relative change in environmental parameter e_j is likely?)
2. What are the magnitudes of the human impact coefficients, b_{jk}? (Given a "unit" change in environmental parameter e_j, what relative change in human parameter h_k is likely?)
3. What weighting schemes, if any, should be investigated? (What are the relative priorities placed on each human activity, h_k?)

Estimation of each coefficient represents answering a specific question that can be presented to one or more appropriate experts by means of techniques for extracting quantitative judgment.

An important and likely question at this point is whether the whole elaborate scheme has any validity. Are the assumptions correct (or at least approximately valid)? Can the impact process by described effectively by the simple staged network of Figure 2? Do the judgments of experts contain valid information? Many more questions might and should be asked, but their answers must await the results of research currently underway or proposed. In the meantime, we offer the method as a powerful way to organize the assessment of impacts of any environmental design project. If the variables can be defined properly, then the numerical results will provide information that is at least as good as that provided by any other approach currently available. If the linearity assumption seems unreasonable for a given application, then let the panel of experts specify the functional forms judgmentally. To be sure, the investigator must ask his questions in a way that will produce useful answers rather than philosophical meanderings, and to judge functions is more difficult than to judge coefficients, but it can be done.

Still, if one is not convinced that the numbers and equations and lists of variables produce meaningful information, then let him disregard the numerical output completely and regard the entire scheme as a gaming technique. By requiring each judge to examine the detailed questions about the impact process, he is led to an in-depth understanding of the alternatives being evaluated. He is also caused to think critically about the impact network, first, when he participates in its construction and second, when he tries to answer the questions it identifies. If his numerical judgments leave him dissatisfied, he is stimulated to expand and clarify himself verbally. If a given question seems overly constricting, verbal reactions are produced. Consequently, if the judges are managed properly, their written comments can be synthesized into a meaningful impact statement. The experts can be guided to produce redesign recommendations which, when supplied to the designers, may serve to direct design modifications. When applied iteratively, the method thus throws the evaluation judges and the entire impact assessment procedure into an interactive relationship with the design process.

If the numbers and equations are accepted, then so much the better. Not only do they provide detailed information about impacts in an orderly way, but they also provide the opportunity for design via deductive reasoning. Under certain conditions it may be possible to solve the equations "in reverse" to specify the design, given the impacts that are desired. Under other conditions, there may be numerous alternatives that yield the same set of impacts, and the impact equations might be used as a set of constraints to bound the design problem. In any case, the method described in this paper provides a powerful conceptual model for approaching and organizing the impact problem.

Illustrative Results from the C-SELM Project

The GPS impact assessment technique is potentially applicable to a wide variety of environmental design problems. It was developed in connection with a regional waste-water management study, and the results of that application are available in detail (Corps of Engineers, 1973; Peterson, et al, 1974; Schoefer, et al, 1974). The method has also been shown to be applicable to transportation systems (Rock, 1974), and is currently scheduled for use in evaluating a proposed highway improvement in northern Illinois. Research is currently underway on an advanced version, GPS2, which will be adaptable to a wider variety of design problems.

In order to illustrate the use of GPS for judgmental assessment of impacts by a panel of experts, the results from the C-SELM study are briefly presented. Emphasis in this section is on the method, not on the systems being evaluated, so the numerical results are presented in a rather general way. Details are available in the project report (Corps of Engineers, 1973).

Table 3 shows the environmental impact profile for three alternative systems. The first is the one with the most negative impact. The second is the reference system, an estimate of how wastewater management in the region would develop without planned regional intervention. It is the "no-action" or "null" alternative from the point of view of regional planning and was defined as having "zero" relative impact levels. The third is the system with the most positive impact. Table 4 gives similar information for the human impact profile. The information on environmental and human impact can be further disaggregated by examining the entire matrix of a_{ij} and b_{jk} coefficients. This would serve to explain why the profiles take on the values they do and would allow pinpointing specific important channels of impact. Tracing through these channels provides detailed information on which system elements are desirable or undesirable, and in what ways, which is directly supportive of redesign efforts. The numbers themselves should be regarded as measures of relative magnitude, not absolute magnitudes. The numbers are expressed relative to the total impact score of the "best" system.

If equation 10 is expressed in matrix terms, it becomes

$$ {}_qH = BA\,{}_qS = C\,{}_qS \qquad (13) $$

where B is the (m x n) matrix of human impact coefficients,
C is the (n x p) matrix of environmental impact coefficients,

${}_qS$ is the vector of design elements in the q^{th} system,

${}_qH$ is the human impact profile vector for the q^{th} system, and

C is a (m x p) matrix of coefficients, c_{jk}, that give the sensitivity of the k^{th} human element to the i^{th} design element.

TABLE 3

ENVIRONMENTAL IMPACT PROFILE FOR THREE PLAUSIBLE SYSTEMS

	SYSTEM		
Environmental Impact Element	Worst	Reference	Best
Recreation and Open Space	12.1	0	31.8
Surface Water Quantity	16.6	0	23.6
Surface Water Quality	15.9	0	22.9
Ground Water Quantity	6.4	0	14.0
Sensory Quality	-3.8	0	12.7
Soil Quality	-0.6	0	12.1
Groundwater Quality	3.8	0	5.7
Residential Land-Use	-2.5	0	5.1
Agricultural Land-Use	-5.1	0	4.5
Com. and Industrial Land-Use	2.5	0	3.2
Biotic Communities	-6.4	0	3.2
Mineral Resources	-15.3	0	1.9
Air Quality	-12.7	0	1.3
Unique or Rare Things	-4.5	0	-7.0
Access	-1.9	0	-7.6
Energy	-31.8	0	-27.4
Total Relative Score	-27.3		+100

TABLE 4

HUMAN IMPACT PROFILE FOR THREE PLAUSIBLE SYSTEMS

	SYSTEM		
Human Impact Element	Worst	Reference	Best
Aesthetics	2.8	0	16.9
Recreational Activity	3.1	0	16.1
Ecosystem Status	4.0	0	15.5
Residential Activity	-1.5	0	8.8
Health and Safety	-0.6	0	8.2
Immigration	-1.1	0	5.9
Food Production	-2.3	0	4.8
Cultural-Educational Activity	-2.0	0	4.1
Population Density	-1.7	0	3.3
Public Service	-1.0	0	3.1
Public Finance	-1.7	0	2.7
Income	-2.5	0	2.5
Private Service	-1.5	0	2.3
Community Political Structure	-1.2	0	2.1
Employment	-3.0	0	2.1
Employment	-1.1	0	2.1
Commercial Production	-3.2	0	0.5
Construction Service	-3.9	0	0.3
Industrial Production	-4.5	0	-1.3
Total Relative Score	-23.2		+100

The coefficients in the C-matrix contain useful information on the link between system elements and human activity impacts, and thus represent another important way to describe those impacts.

In the C-SELM study, statistical analysis of the C-matrix demonstrated that it had a rank of approximately three. This means that the nineteen-element human impact profile for each system can be replaced by a three-element profile without a significant loss of statistical information. The three-dimensional profiles for the best, worst and reference systems are shown in Figure 6. The economic score is primarily a composite of income, employment, commercial production, and industrial production. The human/ecological dimension is primarily a composite of residential, immigration, cultural-educational, health and safety, recreation, aesthetics, ecosystem status, and community social and political structure. The third effect is related mainly to food production.

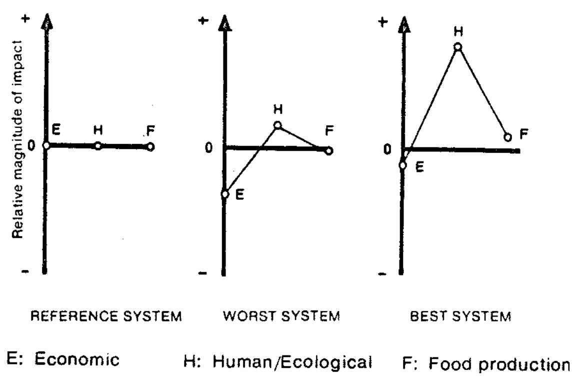

Figure 2

Profiles of the reference, worst, and best systems in three independent dimensions of social impact.

This way of presenting the data provides a simple summary of comparative impacts. The statistical technique (factor analysis) used to collapse the matrix also sheds light on the weights that are implicitly assigned to the impacts by the way the variables are selected and defined.

If each panelist estimates every coefficient in the network, as was the case in the C-SELM study, it becomes possible to answer several interesting questions about disagreement among the judges. Each expert brings a specialized point of view to the problem. By applying equation 10 to the estimates provided by a given expert, the impact can be described and analyzed from his point of view. Comparison of either aggregate results or specific coefficients can be made among judges. Major disagreements or extreme views thus identified can be taken back to the experts in the form of further questions for explanation. Disagreement among two judges does not necessarily mean that one is wrong. It is possible that each has seen a different piece of the same puzzle. Inter-judge comparison and discussion will help to clarify and resolve such problems; it is in the nature of the method, however, to insure that this richness of information is preserved for analysis.

In addition to simple comparative methods, factor analysis was used in the C-SELM study to describe the structure of different points of views represented on the panel. It was found that the thirteen experts were bringing at least seven distinct points of view to the problem, and that the several points of view were not represented equally. It was possible 1) to classify the judges into subgroups, vis-a-vis their perception of the impact process, 2) to clarify the substance of their differences, and 3) to open up these issues for explanation and resolution through discussion. Thus, it is possible not only to identify, describe and perhaps resolve disagreements among judges, but also to test the composition and balance of the panel.

Regarding the reliability of the estimated coefficients, the C-SELM data provide encouraging information. The composite B-matrix coefficients, obtained by averaging the individual estimates of the thirteen judges, were found to be 97% reliable based upon analysis of parallel estimates of the B-matrix, separated by about a six month period. A totally independent multidisciplinary panel of 28 graduate students also estimated the B-matrix. Between the two independent panels, the average coefficients were 91% reliable. This varies somewhat from variable to variable, however, and Table 5 shows the level of reliability estimated for each of the nineteen human elements. By "reliability" we mean the percent of the information contained in the estimated coefficient that can be regarded as correct and stable. Thus, 97% is a liberal estimate and 91% is conservative.

TABLE 5

RELIABILITY OF B-MATRIX COEFFICIENTS BY HUMAN ELEMENT

Element	Estimated Reliability*
Industrial Production	98%
Employment	97
Ecosystem Status	96
Construction Services	96
Aesthetics	95
Food Production	94
Cultural-Educational Activity	92
Health and Safety	92
Recreational Activity	91
Commercial Production	91
Immigration	87
Residential Activity	84
Public Finance	82
Population Density	81
Income	79
Private Service	77
Public Service	75
Community Social Structure	57
Community Political Structure	54

*As estimated by comparing average coefficients from two completely independent panels of judges.

During the estimation process, the C-SELM judges were continually invited to prepare written comments on such issues as:

(a) deficiencies of the GPS technique;

(b) impacts and impact processes which were not well represented in the GPS process;

(c) reasons behind extreme negative or positive impact estimates;

(d) ideas for the redesign of alternative systems.

It was found that these comments were extremely rich in information content, providing detailed insight into many of the impacts (e.g., what specific facilities would be affected and how), and specific redesign suggestions which were often utilized in the next design round. Based on this experience, we conclude that the judges used the framework of the GPS process to develop an in-depth understanding of the systems and their impacts. Furthermore, the written comments were found to be an integral part of the informative output of the method.

Conclusion. The method as presented above is intended for objective evaluation of projects by way of scientific understanding of impact processes and/or systematic judgmental estimation by appropriate experts. It has proven to be an effective means for directing the attention of experts to disaggregate details of impact while preserving an awareness that the impacts occur in the context of a complicated network of interactions. The method reduces judgment to a manageable task, yet it preserves analytically some degree of realistic complexity. The numerical results themselves, when presented in disaggregated tabular (matrix) form, have been found to be especially useful in identifying those components of projects which give rise to favorable and unfavorable impacts as well as identifying the nature of those impacts. Once the methodology has been adapted to the needs of a particular project, numerical estimates of the impacts can be made and reported within a short time-span. This characteristic facilitates the use of the method in a design-interactive mode, whereby preliminary plans or designs are subjected to evaluation and the results, along with redesign suggestions from the evaluators, fed-back to the planners or designers for their consideration.

Experience has shown that the methodology can be readily explained to and understood by audiences having diverse backgrounds and capabilities. Because of this, another extremely promising application is in assessing community perception of impact for the purpose of (1) identifying and clarifying issues and sources of conflict, and (2) educating the public and stimulating informed public participation. This can be accomplished by substituting a community group for the panel of experts. In fact, the perception of impacts held by any group can be determined effectively in this manner. The results can be compared among groups and used to develop information for clarifying misconceptions about system designs and their impacts. The procedure will also serve as an effective catalyst for involving the public in the design process. The authors are currently developing the method for community perception application in Chicago with respect to transportation impact issues.

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