File with: Publications by JNW - 1976

John N. Warfield

EXTENDING INTERPRETIVE STRUCTURAL MODELING

John N. Warfield
Forsyth Professor and Chairman
Department of Electrical Engineering
University of Virginia
Charlottesville, Virginia 22901

Prepared for the Seventh Annual Pittsburgh Conference on Modeling and Simulation, April, 1976

Published in: Proceedings 1976 Pittsburgh Conf. Modeling & Simulation, Inst. Soc. Am., pp. 1163-1167.

EXTENDING INTERPRETIVE STRUCTURAL MODELING

John N. Warfield
Forsyth Professor and Chairman
Department of Electrical Engineering
University of Virginia
Charlottesville, Virginia 22901

ABSTRACT

Continued development of interpretive structural modeling involves increasing both its use and its usefulness. Its use can be increased by providing increased understanding and increased help in the use of the process for the non-mathematical user. Successful application depends critically on good leadership. The demands on leaders are not heavy, but are unusual. Increased training of leaders is highly desirable. Usefulness of the process can be increased substantially. More and better computer programs are needed. Further development of the theory of cycles and examples of use of existing cycle theory will be beneficial. Development of an algorithm, a computer program, and hardware capability for computer construction and display of interpretive structural models would greatly expand the value of the process for users.

INTRODUCTION

Interpretive Structural Modeling (ISM) is a computer-assisted learning process that helps groups structure their collective knowledge. Its development was motivated by a desire to improve the effective use of knowledge in situations where groups of people are involved in interactive learning or decision-making with respect to some complex system or issue.

Its development grew out of a series of projects which began with an effort to organize systems engineering methodology[1]. Next followed the development of a plan for a study to focus on complex societal problems[2]. It was recognized that teams of people would necessarily be working on such problems, and that there was not available much useful background for the constructive conduct of group effort on complex matters.

Graphical methods of information presentation were seen as a major requirement to facilitate the work of groups. A graphical scheme called "unified program planning" was developed, which involved a chain of interaction matrices[3]. This scheme was viewed as a contribution to planning methodology. However it had several shortcomings: the information was too densely presented for effective communication, the interactions were not directionally oriented, the manual development of the matrices was very time consuming, and the method left considerable opportunity for inconsistency and errors in information handling.

To introduce direction, the concept of hierarchy was examined in depth, and a rigorous definition of it was developed. Generalization of the hierarchy concept to multilevel structures followed. Various special types of structure were identified and defined in some detail. The application of structuring concepts was considered in relation to specific societal problems[4]. The concepts of level and cycle in structure were defined and used to help make the graphical presentation more organized and easier to portray. In this way, the first two shortcomings mentioned earlier were considerably ameliorated[5].

To ameliorate the last two shortcomings mentioned, the use of the computer and associated interactive and display equipment as an aid in developing the matrices and handling the data logistics was clarified. Algorithms were discovered that showed how to carry out the necessary activities, and these were reported in detail[6],[7],[8],[9],[10]. These algorithms were not intended to be optimal for computational purposes, but they were intended to be suitable for learning processes and took into account requirements for effective group effort in working with complex subject matter.

Experimental computer programs for carrying out some of the necessary operations in ISM were developed and applied, under the initial leadership of D. Malone.

Attention was then given to effective ways of developing the needed input information for the ISM process. One approach that has proved useful is the method of brainwriting[11] developed by Geschka, et al. A number of experimental applications of the ISM process then demonstrated that the process was functional in real situations. Several investigators reported on their experience with the process, and demonstrated that it could be applied in a rather wide variety of situations[11].

Methods of relating the ISM process to policy analysis and synthesis were reported, to help clarify the potential for the process and its relation to the way in which policymaking might be done. Considerable emphasis was placed on participative policymaking, though contrasting approaches to policymaking were identified[12].

Finally an aggregate treatment of ISM in relation to planning and policymaking was developed, in which the application to societal systems was of primary concern[13].

PROMOTION AND IMAGE

In the early experimental studies with ISM, a conservative approach was taken to its promotion as a useful systems methodology. The initial computer programs were experimental, and did not permit full use of ISM in the manner ultimately intended. The programs were not a complete set; no provision was made for cycle resolution, nor did the programs provide for computer-assisted amendments to initially developed structures. There was much uncertainty concerning user reaction and computation time, and a great desire to avoid subjecting the methodology to severe tests in critical societal areas when its full power was not developed in the form necessary for most effective use.

This conservative reticence is still appropriate, because a full set of thoroughly tested computer programs is still not available. Hence a thorough test of the full methodology remains to be carried out, though there is continuing development. Since there have been more than 60 experimental applications, most of these being judged successful, it now seems safe to say that the process has proved its usefulness, even in the present state of its development. It is believed that its full development is assured, with only the timing and extent of application remaining uncertain.

In retrospect, it is possible to identify quite clearly the desired and undesired images of the ISM process. It is desired that it be viewed as a computer-assisted learning process, with involvement of learning participants as a principal feature. It is desired that it frequently be highly visible in action and iterative in nature. It is believed that it has a wide scope of application, simply because learning does.

It <u>is not</u> desired that ISM be viewed as unaccessible to the layman, as a mathematical tour de force, as a proprietary methodology, or as a self-contained total system methodology. It clearly is not a process that, of itself, will solve societal problems. There has been a growing trend to treat methodologies as though they were human, and to assign credit or blame to them for the way in which they are applied or for the results obtained through their application. Certainly these are false attributions, and are partly responsible for much of the criticism of systems methodologies in general. They frequently are oversold (often by people who do not understand them in depth), and the results of their use are often less than what was promised. Both of these defects quite properly should be assigned to the promoters, who should know that methodologies are like the tools of a carpenter. They are instrumental, even vital, to good carpentry, but they neither make promises nor build houses.

Because of its iterative nature, ISM cannot be said to have a specific number of steps. While it certainly has an identifiable beginning, it does not necessarily have a well-defined ending, any more than learning does. Certainly ISM can be envisaged in disaggregated form to include the following: selection of an issue or system to be explored, generation of an element set germane to that topic, selection of one or more contextual relations to be used as the basis for structuring, editing of the element set and (if necessary) of the contextual relation, matrix filling, computation of the structure, portrayal of the interpretive structural model or "map", examination of the map, and iteration involving the repetition of some or all of the foregoing to the extent deemed necessary. In spite of the amount of effort needed, it is often possible for the computer-assisted group to run through a complete session involving all the foregoing except iteration in one or two days. The time will depend on the complexity of the subject matter.

In its present state of development, the most crucial factor in its effective use is the quality of leadership provided in sessions where it is used. Second only to this is the motivation of the group to learn and to achieve, and the willingness to accept the rather modest constraints placed on the group as the price paid for gaining the benefits of using the process.

APPLICATIONS

Among the interesting applications of ISM can be mentioned Waller's work with a city council and his study of the learning disabled[11], Christakis and Malone's work relating to urban systems[11], Arnstein and Christakis' compilation relevant to technology assessment[14], and an ongoing study by Fitz and his colleagues of the Sahel problem. The latter is the most extended application to date of the ISM process.

Experimental applications have been made in international, national, regional, state, and local government planning, research, or policymaking studies; in industry; and in education. These are believed to be sufficient to illustrate the potential use in all these fields.

COMPUTER PROGRAMS

Six classes of computer programs are needed for full use of ISM. There is some overlap among the classes, so the description given below identifies programs by letters to indicate the overlap.

<u>Developing the Initial Structure</u>

One pass through the process, involving no iteration, leads to an initial structure. The programs needed are:

A. Load the elements and the relation
B. Edit the element set (interactive)
C. Fill the reachability matrix (interactive)
D. Compute and print the levels, cycles, and connections

Programs to accomplish these functions are available in experimental form, and have been used in numerous ISM sessions.

Resolving Cycles

Four programs are useful in resolving cycles that are discovered in the initial structure. These are:

E. Fill the weighting matrix (interactive)
F. Compute threshold matrices
G. Compute geodetic cycles
D. Compute and print the levels, cycles, and connections

Programs have been written and applied to perform all these functions except, possibly, E. They have been less widely used than those aimed at developing the initial structure.

Interconnecting Two Structures

The interconnection of two structures can be accomplished, in principle, without additional programs. However in the interests of efficiency, it is desirable to have a program that allows interactive filling of an interconnection matrix. The two programs of principal interest in interconnecting two structures are:

H. Fill interconnection matrix (interactive)
D. Compute and print the levels, cycles, and connections

Making Format Amendments

It is desirable to have the capability of amending the format of a structure[13]. The programs needed are:

I. Contract the structure (interactive)
J. Pool within the structure (interactive)
K. Substitute within the structure (interactive)

It is believed that no programs have been written to accomplish these functions.

Making Substantive Amendments

Format amendments simply change the way in which the map is displayed, but substantive amendments modify the intellectual content of the map. It is believed to be highly desirable to make such amendments only to cycles or to hierarchies, and not to multilevel structures in most general form. The programs needed are:

L. Add a new element to a cycle (interactive)
M. Remove an element from a cycle (interactive)
N. Add an element to a hierarchy (interactive)
O. Remove an element from a hierarchy (interactive)
P. Add an edge to a hierarchy (interactive)
Q. Remove an edge from a hierarchy (interactive)

It is believed that no programs have been written to accomplish these functions.

Drawing the Map

In the interests of effective use of ISM, it is highly desirable that the computer have the capability to draw the maps developed by the group through response to computer questions. Unfortunately there has been no significant work on this problem. It is not clear that suitable hardware exists for accomplishing the function. Moreover no algorithm is available that demonstrates how the computer might develop the layout with a minimum of line crossings (for best readability).

To accomplish this function, two additional programs are needed:

R. Compute layout of map
S. Draw the map

Until these programs are available, ISM will operate well below its ultimate potential. It is important to recognize this, because in the absence of this capability the evaluation of ISM as a learning process will necessarily be considerably biased by the relative inefficiency of working with the maps produced. Much of this work now is manual and subject to human errors, inconvenient displays, and time delays. Time delays are quite expensive when groups are involved; particularly when the group is drawn from varied geographic locations.

EXTENDING THE PROCESS

Extensions of the ISM process can be considered in two rather different, but interdependent, ways. First, increased use of the process can be considered as an extension. Even in its present state, it is reasonable to believe that considerably greater use of the process is both feasible and desirable. Second, improvements in the process can be thought of as extensions. Increased use will stimulate improvements in the process, and improvements will stimulate increased use.

Increasing the Use of the Process

The use of the ISM process can be increased in three principal ways. These are: provide more help for the potential user, develop leaders capable of facilitating the use of the process, and develop increased understanding of the process. The kind of understanding needed at the technical level can be expected to evolve through normal scientific and educational channels[13], given time for the evolution. At the user level, there may be no interest in the technical details of the process, but only a desire to know whether any beneficial outcome can be expected from its use, what the nature of such outcomes might be, and what is required to use the process effectively. Unfortunately there does not now exist an appropriate process description carefully tailored to the lay user. Instead it has been necessary to convey such information spontaneously, on demand.

Hopefully this situation will be rectified, but it will be most beneficial if such a description includes a sample case study that is more inclusive and representative than any published so far. Also such a description would, ideally, take account of the recommendations made in the next section.

Methods of Helping the General User. The general user of ISM will be helped by a number of potential developments. These include the identification, definition, classification, and clarification of contextual relations suitable for use in ISM sessions. Also some study of element definition would be helpful. Further development of specialized types of interpretive structural model would help users. One such type, the intent structure, has been rather widely used. It is much easier to learn the special types than to gain understanding of multilevel systems in general. Among the necessary steps are the conception, definition, and illustration of special types.

A certain amount of readiness training is very helpful for participants. This could be achieved by developing a simple, standard training exercise. The development of such an exercise should receive considerable attention. Some of the exercises that have been used experimentally can be highly misleading, teaching not only what is desired but also conveying undesirable images. The goal of the exercise should be to develop a good understanding of how the process evolves, with emphasis on the role of the participants. It should not bring into play cognitive loads that detract from and go well beyond the aim of the training exercise.

Machine-constructed displays would be extremely helpful, even in training exercises. As mentioned, this capability remains to be developed. In its absence, a training exercise should include a full explanation of the products of the exercise. For purposes of developing user perspective, the existing limitations on computer-assisted amendment of maps should be carefully explained. Among other things, this will help the user appreciate the need for followup that cannot now be done with machine assistance.

Developing Leaders. Given the critical assumption that the hardware component of the ISM exercise is fully operational and performs reliably throughout the exercise, it can be said that the most critical factor in determining the success of the process is the quality of leadership provided. When the issue being explored is sufficiently simple, the hardware can be dispensed with. But the leadership is critical.

In many ways the burden placed on the leader of an ISM process is considerably smaller than that placed on the leader of a discussion group. The machine does much of the sequencing, and focuses the group activity. But the simplification of the leadership role is a mixed blessing. Leaders accustomed to playing a more vigorous role, or a more involved role, may well be unable to retreat to the level of strict group facilitation which seems to be required in conducting ISM sessions. The process calls for a kind of leadership that intervenes very modestly, does not overreact to user behavior, provides mainly a support and expediting function and then only when clearly needed, and avoids many of the classical forms of leadership behavior. This kind of leadership is best when it recognizes what to avoid in leading the process. In a process painstakingly designed to minimize cognitive load on its users and to provide focus for good group discussion, it is critical not to reassert the kind of cognitive loading that was a principal motivation for developing the ISM process in the first place.

It may be more important to establish criteria for selecting personalities to provide leadership for ISM sessions than methods for training leaders. Nevertheless certain training is required. Hence the development of a modest program for training leaders would be quite beneficial in extending the use of the process. It is suspected that such training could be carried out in a day if the individuals involved possessed personality characteristics amenable to the low-intervention type of leadership required in conducting the ISM exercise. It will be necessary to keep in mind that the participants in these exercises often possess leadership skills themselves, and if given the opportunity to exercise them in relation to the specific focus of the exercise at appropriate times, the learning aspects of the process can be greatly enhanced.

Improving the Process

Improvements in the ISM process can be considered by supposing that the process involves conceptual theory, algorithms, computer programs, and behavior. The behavioral aspects of the process have already been discussed to some extent in the discussion of leadership and readiness training. Behavioral research on the process from an observational perspective has been negligible. Perhaps the most that can be said concerning behavioral aspects is that the development of conceptual theory, algorithms, and programs all benefit from a concern for the user. The role of the user should be carefully considered and, to the extent possible, such developments should provide benefit to the user of the process. The minimization of cognitive load is the goal most likely to be subverted by arbitrary technical modification of the process. This goal is absolutely critical, and any development that works heavily against it must be rejected.

Among the desirable developments that would hold considerable potential for improving the process are the further explication of the theory of cycles, particularly as it might relate to interactive work involving computer-assisted group learning in the study of cycles. Also more and better computer programs are needed. Such programs should be efficient, and should be attractive in an interactive user environment. The most essential algorithm requiring development is one that will enable the computer to lay out and draw the maps generated in the process in such a way that they are most readable to the user.

In addition to these extensions which would be aimed at improving the internal aspects of the process, it would be helpful to work at the output stage of the process to couple it to the main stream of certain related work. In particular, it would be helpful to develop interactive algorithms whereby a structural model could be the beginning of the evolutionary development of more quantitative models of various kinds. The type of user of such algorithms might be quite different from the norm. The details of this improvement presumably would be of interest mainly to specialists, such as persons who create economic models, manpower models, dynamic models of firms or larger social units such as cities or nations. Many would be interested in inspecting in detail the reasoning behind such models. The ISM process and the maps produced would be very illuminating adjuncts, adding greatly to the value (and perhaps to the credibility) of such models.

CONCLUSIONS

Interpretive structural modeling (ISM) is a partially-implemented, computer-assisted learning process that helps groups structure information. The process, in its partially-developed state, has been tested and found useful in a variety of applications.

Continued development of the process involves increasing both its use and its usefulness. Its use can be increased by providing increased understanding and increased help in the use of the process for the non-mathematical user. Successful application depends critically on good leadership. The demands on leaders are not heavy, but are unusual. Increased training of leaders is highly desirable. Usefulness of the process can be increased substantially. More and better computer programs are needed. Further development of the theory of cycles and examples of use of existing cycle theory will be beneficial. Development of an algorithm, a computer program, and hardware capability for computer construction and display of interpretive structural models would greatly expand the value of the process for users.

ACKNOWLEDGMENT

Support of the National Science Foundation, Grant ENG75-17609, in the preparation of this paper is gratefully acknowledged.

REFERENCES

(1) Warfield, J. N. and J. D. Hill, A Unified Systems Engineering Concept, Battelle Monograph No. 1, June, 1972 (edited by B. B. Gordon).

(2) Dayton, R. W., E. R. Irish, and J. N. Warfield, "Developing Improved Methods for Dealing With Complex Societal Problems", Battelle, Columbus, Nov. 23, 1971.

(3) Hill, J. D. and J. N. Warfield, "Unified Program Planning", IEEE Trans. on Syst., Man, and Cybern., 2(5), 1972, 610-621.

(4) Warfield, J. N., An Assault on Complexity, Battelle Monograph No. 3, April, 1973.

(5) ________, "Binary Matrices in System Modeling", IEEE Trans. on Syst., Man, and Cybern., 3(5), 1973, 441-449.

(6) ________, "Developing Subsystem Matrices in Structural Modeling", IEEE Trans. on Syst., Man, and Cybern., 4(1), 1974, 74-80.

(7) ________, "Developing Interconnection Matrices in Structural Modeling", IEEE Trans. on Syst., Man, and Cybern., 4(1), 1974, 81-87.

(8) ________, "Toward Interpretation of Complex Structural Models", IEEE Trans. on Syst., Man, and Cybern., 4(5), 1974, 405-417.

(9) ________, Structuring Complex Systems, Battelle Monograph No. 4, April, 1974.

(10) ________, "Implication Structures for System Interconnection Matrices", IEEE Trans. on Syst., Man, and Cybern., 6(1), 1976, 18-24.

(11) Baldwin, M. M., (Ed.), Portraits of Complexity, Battelle Monograph No. 9, June, 1975.

(12) Warfield, J. N., "Profiles of Metapolicy", Proc. 1975 IEEE Conf. on Cybern. & Society, IEEE, New York, Sept., 1975, 1-4.

(13) ________, Societal Systems: Planning, Policy, and Complexity, Wiley-Interscience, New York, 1976.

(14) Arnstein, S. R. and A. N. Christakis, Perspectives on Technology Assessment, Science & Technology Publ., Jerusalem, Israel, 1975.