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Appendix B

INTERPRETIVE STRUCTURAL MODELING

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1. Introduction

Interpretive Structural Modeling (ISM) is a methodology with an attendant computerized tool which has been developed over the last decade by John Warfield and some of his co-workers. The principal reference in this area is Warfield's recent book Societal Systems (1976). Extensive references to other pertinent literature are contained in the book.

ISM is intended to assist in the consideration of a set of elements according to some selected relation pertaining to the given problem context (thus, called a "contextual relation"), and to develop an "organization chart" representing the way the elements are interconnected according to that contextual relation. The specific organization chart that results depends upon the relation chosen, as well as the set of elements involved. For example, if one were considering the group of employees in some business, the contextual relation "is subordinate to" would have attendant with it an organization chart of the type normally used in the business environment. However, if in considering the same group of people the contextual relation "is younger than" were used, most likely, a different organization chart would result.

ISM does not seem to have found its way to applications in TA as yet. This may be explainable by the fact that, to date, only a relatively small number of investigators around the country have applied ISM to "real-world" problems, and due to their particular time, interest, and/or circumstances have not been involved in TA efforts. Alternatively, one might imagine

that ISM has not been used in TA applications because it simply is not a suitable tool/methodology for these applications. After analyzing ISM for its potential application to TA, this latter alternative is dismissed; the present reviewers feel that ISM definitely has potential for use in the TA process. There are possible hazards and/or pitfalls that the prospective user should be aware of; an attempt is made herein to point these out, and to offer what advice is possible at this time for avoiding or minimizing them.

Fitz (1975) has described ISM as consisting of three component technologies, namely, a mathematical technology, a computer technology, and a social technology. To quote:

> The mathematical technology of ISM consists mainly in the theory of binary digraphs and their associated matrices. This theory has been developed and integrated by John Warfield in his monographs.
>
> The computer technology of ISM consists of two subcomponents, namely, software packages... and a hardware configuration which facilitiates the interaction between the user and the computer...
>
> From (one) point of view, the social technology of ISM, i.e., the technology of designing appropriate environments for effective group exploration and learning, is the most important (emphasis added). In the long run, the utility and durability of ISM as a technology of social learning will depend on the thought and skill that is employed in developing the social technology.

The chief assumptions that are made by ISM are that

1) It is valid to consider pairwise-only interactions among the items on the list;

and

2) The relations satisfy the transitivity condition.

As an example of these assumptions, consider a list containing elements a, b, c and d along with the contextual relation "is taller than." It is clear that for this case there is no inherent difficulty with asking the question of tallness on a two-by-two basis, i.e., Is a taller than b? Is b taller than c? etc. Further, it is clear that this relation is transitive; that is, if a is taller than b, and b is taller than c, then, it follows that a is taller than c. (In short hand, letting R stand for the contextual relation, we have: if aRb and bRc, then aRc.) A consequence of the transitivity property is that once it has been determined that aRb and bRc, then it is not necessary to ask whether aRc.

The basic power of the ISM tool rests upon this transitive property of the contextual relation. The ISM computer program proceeds under the assumption of transitivity and, by way of a fast and accurate bookkeeping, asks only those questions that are necessary, often reducing the complexity and work involved by a factor of 10. A simplified description of the ISM process is as follows:

1. A set of elements pertinent to the issue is derived from the situation under consideration, a phrase describing a particular relation of interest to the situation is chosen for linking the elements, and a concise statement of the issue context is written.
2. The computer tabulates all the participant responses to a series of pairwise queries which it makes until all elements have been related to each other.
3. The computer uses the accounting which it has kept of all the responses in the ISM program to print out the necessary information for the construction and display of a structured visual representation of the elements in accordance with those judgments made by the participant(s).

4. This "organization chart", through either discussion or iteration of the entire ISM process, may be interpreted, corrected, or revised in any manner the participant(s) might consider necessary or desirable.

2. Discussion

Most of the other discussions in these appendices present the underlying mathematical theory for the method being considered, and go into detail concerning the computer implementation and the process of using the given tool. In the present case, however, it was decided not to take this approach, because among other considerations (e.g., see next paragraph), there is an extensive literature already available concerning ISM. In particular, the reader is referred to Warfield's book Societal Systems for broad coverage concerning ISM, including a development and discussion of the mathematical theory which underlies the processing that goes on inside the computer program(s) used to implement ISM.

There is considerable theory underlying the computer implementation of ISM, but knowledge of this theory by the user does not materially improve his/her understanding of what ISM is all about and/or of the output generated by ISM. It is basically only necessary to understand the (very few) assumptions made by ISM, the fact that a hierarchical type "organization chart" of the relations among the elements considered is being sought, and that the purpose of the assumptions is for the computer program to take advantage of some nice attendant mathematical properties which significantly reduce the number of comparisons the user has to make.

The discussion herein is organized around a list of ten topics which are seen to represent the key dimensions of ISM as a tool and as a process. Some of these are foundational to the process, and some (e.g., items 7, 8, and 9 in the list) are included because these have been suggested as potential problems with ISM. Key aspects of each of these items are discussed so the reader, as a potential user, may be sensitized to the basic issues at hand. In addition, some "helpful comments" are included where appropriate; the latter were distilled from various interviews held with users of ISM around the country (in particular, with Fitz, Malone, Waller, Warfield and in-house users).

The ten topics are:

1.) Element Set
2.) Contextual Relation
3.) Pairwise Requirement
4.) Transitivity Requirement
5.) Software Implementation
6.) Process: Behavioral Component; Leader/Facilitator; Iterative Nature
7.) First-Element Syndrome?
8.) Voter Paradox?
9.) Reachability Matrix/Minimum-Edge Digraph: Adequate for Dynamic Modeling?
10.) Cycle Resolution

2.1 The Element Set

As in the case of the other SM tools in this report, a distinct activity (generating phase) is required to develop at least an initial set of elements pertinent to the issue being considered. With ISM, this initial list can be augmented and/or modified 1) during the early stages of an ISM session, 2) after a complete cycle through the ISM procedure, and/or 3) during a pretest phase that might be carried out before convening the actual ISM session.

Of course, a description of the problem (as understood at the time of the exercise) must be at hand as a prerequisite to the generation of the set of elements used in the ISM sessions.

2.2 Contextual Relation

The relation chosen for the ISM exercise is dependent upon, and really has meaning only in, the context of the problem being considered. Accordingly, the relation is called a "contextual relation". The ISM process is based specifically on the assumption that the contextual relation is transitive. There should be direct consideration given to the contextual relation to determine that it is transitive, or that it is "sufficiently" transitive that the exercise is likely to be useful. There is no guarantee that the ISM process will be applicable to a contextual relation chosen just because it is relevant.

Warfield (1976, p. 348) states that

> It has frequently been found possible to construct a transitive contextual relation that is quite satisfactory in exploring a particular issue in instances where the original choice was not very satisfactory...even when it cannot be demonstrated that a contextual relation is inherently transitive, it may be quite feasible to employ the assumption of transitivity to develop an initial structure. But if such a course if followed, it should be done knowingly.

The choice of the contextual relation and the elements go hand-in-hand, in the sense that both depend upon the problem specification, and are selected with solution and/or greater understanding of the problem in mind. The specific aspect of the problem to be addressed dictates the appropriate contextual relations to consider and the types of elements to be used.

Examples:

In a planning context, the set of elements might be a list of goals, and the contextual relation "is more important than."

In the social arena, a problem context might be stated as "Citizen Insecurity in ABC Neighborhood" (Fitz 1975). In this case, the "elements" might be a list of the most important "sub" problems within this context, i.e., youth drug abuse and addiction in the neighborhood, major thefts, murders, vandalism, good market for stolen goods, broken families, etc. An appropriate contextual relation might be "aggravates or intensifies", e.g., youth drug use "aggravates or intensifies" youthful vandalism (as a problem).

The discussion in the section on transitivity gives some examples of candidate contextual relations.

2.3 Pairwise

ISM requires that the given elements be considered two-by-two using the given contextual relation. There are situations where this type of comparison is not appropriate, so tools such as ISM cannot be used.

Whether or not a pairwise comparison is appropriate is sometimes determined not only by the problem context, but by the specific contextual relation. For example, consider a problem in a manufacturing context where the list of elements includes: production level, labor force available, and plant capacity. If the contextual relation being used is "contributes to," then a pairwise relating of labor force to production

level, and of plant capacity to production is acceptable. But, if the contextual relation is "is determined by," then a problem arises: production level is determined by labor force and plant capacity (among other things), so a simple pairwise question is not appropriate. (Incidentally, the contextual relation "is determined by" may not be even transitive, depending upon the context within which it is used).

In some cases, even if the pairwise assumption is not strictly correct, it may be reasonable to tentatively make the assumption to create an initial structure from which to carry on further investigations. It is important to consider this pairwise issue very carefully before embarking upon an ISM exercise.

2.4 Transitivity

As mentioned earlier, the fundamental assumption upon which ISM rests is that of transitivity of the contextual relation being used. One of ISM's main attributes is its ability to greatly reduce the number of pairwise relations the user is required to look at; this attribute depends directly upon the transitivity property. Incidentally, if in addition to being transitive, the contextual relation is known to be asymmetric -- i.e., if aRb, then not bRa -- then the number of comparisons can be further reduced.

Also as mentioned above, transitivity depends upon the contextual relation being used and the nature of the elements themselves.

The following discussion concerning transitivity as it relates to ISM is quoted from Warfield (1976, pp. 295-296):

The theory of structuring, as developed herein, makes extensive use of the property of transitivity. This use is properly viewed as a restriction on the applicability of the theory, but there are several reasons why this restriction is not severe.

Many important contextual relations either have the property required for transitivity, or can be modified somewhat so as to acquire this property. The precedence relation clearly has this property. It is difficult to imagine how a universe in which precedence lacked transitivity could operate, since without it all sense of time would seemingly be destroyed.

The inclusion relation clearly is transitive. Were it not so, the universe would lack organization altogether, and there would be no basis for development of any of the sciences. While the relation "causes" is not necessarily transitive, the relation "impacts" would appear to be transitive in virtually all imaginable situations.

Transitivity of the relation "implies" is at the basis of most human reasoning. One of the characteristics of complex situations is that the structure of implication involved in sorting out issues is extremely difficult to create through an unaided exercise in thinking or through bare dialog. The term "linear thinking" has sometimes been used, very likely to suggest a special kind of hierarchical structuring where there is only one element in each level, and it seems axiomatic that such structures would be easier to construct in the mind than those that have multiple elements in the levels, some of which may be involved in cycles.

Experience suggests that transitivity of relations is so prevalent that there is a tendency to assume it even when it does not apply. The contextual relation "is preferred to" has often been used as an example of a relation that may or may not be transitive. Preference is subjective, and subjective relations may or may not be transitive. Thus, if a person says "blue is preferred to red" and "red is preferred to yellow," it may still be that "yellow is preferred to blue"; hence transitivity is violated. It is appropriate to speak of "transitive preference" and "intransitive preference."

Even when a contextual relation is not known to be transitive, the methods described here may still be applied sometimes as a means of arriving at a transitive structural model, if the developer is careful to examine and modify the result.

2.5 Software Implementation

There are two major algorithms developed by Warfield for carrying out the ISM process. One is known as the "Partitioning" (or, "Lift-Set, Drop-Set") algorithm, and the other as the "Bordering Algorithm." There are considerations as to when each is "best" to use; Warfield (1976, pp. 323-325) gives a discussion comparing the two.

Suffice it here to say that the earliest implementation, originated at Battelle Memorial Institute, (Warfield 1973), is based upon the Partitioning Algorithm. The more recent implementation at the University of Dayton, (Fitz 1975), utilizes the Bordering Algorithm. Discussion with various users of ISM around the country indicates that the latter is the preferable one in most applications. Therefore, users are advised to obtain the University of Dayton version and then, if practical, to also implement the Battelle version. There are times when one is better than the other.

The most direct statement that one can make in favor of the Partitioning Algorithm is along the following line: The Partitioning Algorithm is better when the users want to accomplish a systematic pass through all the elements for the purpose of editing the initial list of elements, and/or to test the appropriateness of the contextual relation used. Relative to the bordering algorithm, its main advantage is that a relatively meaningful sub-structure is available to the users after each element is considered. However, empirically it can be stated that it is usually better not to show this information to the (Role III)*

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*See Chapter II, Section F, in Volume 1 of this report.

participants at each new stage when it is available. This information tends to restrict the thinking of the participants, and they tend to (subconsciously, at least) take over some of the information processing load intended for the machine. Thus, the substructures should be shown to the participants only at judiciously selected points in the process. Based on user experience, it seems that there should be at least 10 to 15 elements processed between each "look" at the sub-structure.

The person filling Role II for the ISM sessions must become knowledgable about the above issues, so he/she is best prepared to guide the Role III persons through the exercise.*

2.6 Process

A large fraction of the benefits of ISM derive from the behavioral component of the process and not the output digraph itself, at least not the one developed at the end of the first cycle.

ISM provides an environment for learning and for communicating, and, it provides an "excuse" to get people together to talk about and share their ideas, in an environment where they are forced to focus their discussion on the particular topic(s) at hand.

The facilitator (Role II) plays an extremely important part in an ISM session. The literature on ISM is fairly unique in that it addresses the issue of the importance of the facilitator (Role II); e.g., Warfield (1976, pp. 351 et seq.).

Since so many behavioral aspects are integrated during the ISM process, care should be taken to not make it a "mechanistic" one. The iterative nature of the ISM process is an important consideration. Participants almost invariably change their opinion concerning certain answers they have previously given after they see the way these interact with the other data they provide as represented in the output graphic (digraph) given by the ISM program. There is very definitely a learning process and more importantly, a sharing of information among the participants, so that this is a participative modeling process, par excellence.

Malone (1975) quotes one of the observers of ISM sessions conducted by him as saying that "the use of the methodology appeared to enhance the quality of interdisciplinary and interpersonal communication within the context; the hardware and software of the methodology tended to focus the attention of the participants on a "neutral" object, namely the query appearing before them on a TV monitor, thus tending to defuse potentially volatile or sensitive aspects inherent in face-to-face confrontation." Malone quotes another participant who said that the aspect of the methodology that impressed him was "that it tends to promote use of information rather than the generation of data."

It is important for an ISM session that the iterative nature be fostered. A building process very definitely occurs. At judicious points, substructures are presented (using the Bordering Algorithm), and they provide a basis for critiquing assumptions going into the digraphs, and they allow changes to be made. Then the process backs up and starts over at the appropriate point (iteration). During the "amending" of the digraphs, certain insights are often expressed. It is important to have a secretary present to record these insights as they occur. These are then used by the facilitator in guiding the remainder of the process.

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*See Chapter II, Section F in Volume 1 of this report.

One concern expressed by potential critics of the ISM process is that the machine might tend to intimidate the users, (e.g., "since the machine says such and such, it must be true."). Those experienced in using ISM in "real-world" situations report that such users are indeed NOT intimidated by the machine; if they have a problem of concern, then their motivation is such that if they don't "like" what they see, they make changes and proceed accordingly (iteration, again). An important aspect which aids this process is a graphic portrayal of the interconnection data. This is not yet automatically produced by the software implementation, but is easily constructed by hand using the information supplied by the computer. It is recommended that a person preparing to serve as an ISM facilitator read and study, as a minimum, Chapter 14 ("Interpretive Structural Modeling") of Warfield (1976).

2.7 First-Element Syndrome?

A concern that is brought up from time to time (e.g., see Watson 1978) deals with the initial organization of the list of elements. It is claimed that the overall grouping of the elements, and in particular the element that appears at the beginning, influences the form of the structure that results from the process. Warfield says that he developed the Bordering Algorithm as a consequence of this concern presented to him from numerous sources over the years, but, in all of his reflections, before and after, he sees no theoretical reason for this to be true. Further, in interviews with users of ISM (e.g., Fitz, Waller, Malone) all agree that there seems to be no empirical evidence to support this concern.

By a fortuitous happenstance, the first element might provide more "inferential leverage" than some other element, and thus result in fewer

questions, but this should not necessarily influence the so called "answer." ISM is an iterative process, and the output graphic most always undergoes modifications. It is reported that the first cycle hardly ever results in a structure that the group accepts; the amendment process is almost always called upon.

If the lead element is ambiguous, there might be more uncertainty in the minds of the participants, and therefore more amending might be required. Further, there might be some biasing in the mind-set created via certain orderings. In either of these cases, the skill of the leader will be called upon to recognize the situation, and to successfully guide the group through the process.

Aside from theoretical considerations, the practical fact of the matter is that the ISM process does build up information as it progresses. The information that is accumulated depends upon the questions asked, and the specific issues the participants think about. Certainly, if a group goes through one cycle starting with one element, and then a second time with a different initial element, a different result ought to be expected, because the second time through the participants have the benefit of the information developed during the first cycle. In fact, this is the basis for the amending procedure so important to the ISM process.

2.8 Voter Paradox?

There is a well known proposition (actually a theorem) in the social sciences that in those situations where voters must vote on more than two items, and must do it on a pairwise basis, then, even if the voters are individually transitive, the group as a whole could be intransitive in its voting. Because of this, the <u>sequence</u> of pairwise voting is important to the final result. (Congressmen are well aware of this, and develop their strategy for introducing amendments to bills accordingly.)

The following is an example to illustrate the point (> = "is preferred to")

<u>Voter</u>	<u>Preference</u>
1	A > B > C
2	B > C > A
3	C > A > B

<u>Via Majority-Rule Voting</u>:

I. A vs. B yields A winner,
then A vs. C yields C winner; C wins

II. B vs. C yields B winner,
then B vs. A yields A winner; A wins

III. A vs. C yields C winner,
then C vs. B yields B winner; B wins

Thus we see that the output result is dependent upon the specific sequence of voting.

If the above situation were present during an ISM session, because of the transitive closure operation performed by the ISM algorithm (dependent upon the assumption of transitivity) the following would obtain:

I. ARB: Yes ⇒ A > B
ARC: No ⇒ C > A
Via transitive closure ⇒ C > A > B

C
↑
A
↑
B

II. BRC?: Yes ⇒ B > C
BRA?: No ⇒ A > B
Via transitive closure ⇒ A > B > C

A
↑
B
↑
C

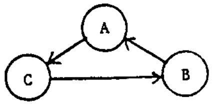
III. ARC?: Yes ⇒ C > A
CRB?: No ⇒ B > C
Via transitive closure ⇒ B > C > A

B
↑
C
↑
A

We note that the resulting structure is not the same in each case.

The example above raises the issue in the previous section, namely the "first-element syndrome?" The output structure here does depend upon the particular first element chosen. <u>BUT</u>, the saving aspect of the ISM process in both cases is the AMENDMENT and reiterative process which is inherent in ISM. The burden, of course, will be upon the facilitator to take the necessary actions to obviate either of these potential traps.

In a situation as clear as the one illustrated above, in each of the three cases, two of the participants will disagree with the output structure, and will most likely make this known (the facilitator must draw this out). When this is done, the facilitator will guide the process to discover that the actual structure is a loop (or cycle), each different voting scheme just having stepped into the loop at a different.



The facilitator ought to be aware of this possibility, and take certain actions to test for it periodically, e.g., by asking various questions at random at the end of each process cycle to see if "cycles" show up in the digraph. If so, then, as shown above, this may indicate intransitivity in the voting pattern.

The main consequence of the voter paradox consideration is to issue the caveat to the users of ISM that it is not a sufficient test that the individuals be transitive to insure that the group is transitive. A concomitant recommendation is that the facilitator should check for this possibility at appropriate places in the process.

An example of a circumstance where an analogous "group intransitivity" could appear is the following:

> An observer is asked to decide which is "noisier" when perceived from the ground on an otherwise calm evening: a Concorde SST, a group of 747's, or a group of helicopters flying overhead (each at their respective usual altitudes).
>
> The observer is asked for a set of pairwise comparisons to come up with an overall ordering. The observer stops to reflect upon each pairwise question (a gestalt type processing?) and provides the investigator with the answers. The investigator is dismayed to find that the observer is "intransitive" in his/her answers.

One explanation for this might be as follows. Although we posit that the observer did not consciously do so, subconsciously the property "noise" might have been broken up into various dimensions, for example, physical intensity, duration, frequency spectrum, etc. Without too much stretch of the imagination, even with just these three dimensions, a situation similar to the previous example could obtain. Namely, if the SST is compared to the 747's, and if the SST "scored" higher on two of the dimensions than did the 747's, then the SST, via an overall impression, would be called

"noisier". Similarly, if the 747's are compared to the helicopters, and the 747's scored higher than the helicopters on two of the three dimensions (not necessarily the same two), then the 747's would be said to be "noisier". Then if in comparing the helicopters to the SST the group of helicopters scored higher on two of the dimensions than the SST, then the helicopters would be judged "noisier" than the SST. This set of answers would result in a cycle as in the previous examples, i.e., an "intransitive" situation.

In this example, by construction, the inner workings are made clear. This is not usually the case. However, from this example, a potentially general operating principle for getting around the problem suggests itself. Namely, <u>disaggregate</u> or unbundle the key variable, in this case "noise", into its component parts. Thus, an operating principle for an ISM facilitator might be, in intransitivity shows up, have the participants look at the contextual variable involved, and determine if a disaggregation can be accomplished. If so, then repeat the ISM process for each of the component dimensions, and proceed accordingly.

2.9 Reachability Matrix/Minimum-Edge Digraph: Adequate for Dynamic Modeling?

As mentioned earlier, the output graph of the SM process (a digraph) is essentially an "organization chart" which shows the relations among the elements. The nodes in the graph represent the elements, and the lines represent the fact that the two elements at the ends of the lines satisfy the contextual relation under consideration (alternatively, a "path" exists between the two elements). One thing that must be kept in mind by the facilitator, and communicated to the participants as necessary, is that the ISM program presents what is called the "minimum-edge digraph" as its output. This means that only the minimum number of paths necessary to preserve reachability are kept in the digraph. If more than one path exists between two nodes, the redundant ones will be removed as long as paths to other nodes are not destroyed. For example, if the "actual" relations were to be properly represented as in Fig. B-1A, then the minimum-edge digraph corresponding to this would be as shown in Fig. B-1B.

Fig. B-1A "Actual Representation"

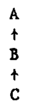


Fig. B-1B Minimum-edge Representation (preserving reachability)

During the amendment process, the facilitator must prod the participants to determine if they intuitively feel that an important path is "missing", and if so, to guide them to discover the path(s) deleted by the ISM program. It is reported that in practice participants are successful in amending the structure to yield one that fits their intuition relative to the problem context.

Earlier it was stated that the user did not have to know the particulars of the ISM computer implementation in order to use ISM. This is true so long as one uses the output of ISM as originally intended, namely, a minimum-edge digraph representing the elements and their interconnections under the given contextual relation.

BUT, if one wishes to use this output in other ways, care must be taken to consider the exact nature of the various forms of the data available in the ISM computer implementation.

One application of the output of ISM that has received some attention (Burns 1977, Fitz and Geiger) is that of building dynamic models. The ISM output digraph guarantees only that "reachability" among elements is preserved, whereas in usual dynamic simulation models, it is required to know "direct" connections between elements. In the parlance of digraph theory, the matrix associated with the "direct connection" digraph is an adjacency matrix (AM), whereas, in Warfield's parlance, the matrix available at the output of the ISM computation cycle is a skeletal reachability matrix (SRM). There are many potential adjacency matrices that correspond to the same reachability matrix. Therefore, it is not possible to guarantee retrieval of some unique AM from the output SRM.

It is possible that useful results can be obtained; the purpose of this discussion is to make the reader (as a potential user of ISM) aware that special consideration is required before effecting this kind of application of the ISM output. The review team was not unanimous in its conclusions along this line, so our main advice is to "be aware".

As an example of the correspondence between a minimum edge digraph, and the "actual" digraph consider a situation consisting of nine elements. In the usual case where an ISM session is to be run, it is assumed that the basic knowledge concerning the connections among these elements resides in the heads of the participants (Role III) as intuitive, or personal, knowledge. For the purpose of construcing an example, ASSUME that the connection information residing in the heads of the participants is as shown in the digraph shown in Figure B-2. It is assumed that this information is not normally directly available, but rather that it is to be ascertained via a series of questions and answers a la ISM.

Let us use "can you get from X to Y" as the contextual relation, where X and Y correspond to different choices of each of the nine elements. This contextual relation is seen to satisfy the requirements that 1) pairwise comparisons are acceptable, and 2) it is transitive. This run on the Partitioning Algorithm Implementation of ISM (the one most readily available at the time this was run), and the elements were considered in straight numerical order. The process required asking 43 of the 81 possible questions to arrive at the output result. The result is shown in Figure B-3.

We observe:

1.) The ISM process has imputed a hierarchical nature to the connections that was not clear in the digraph of Figure B-2. This hierarchy is dependent upon the contextual relation used to carry out the inquiry; element 4 at the "top" has a path to all other elements, whereas none go into it; element 8 at the "bottom" has a path to none of the other elements, whereas all other elements have paths to it.

2.) It is the nature of the process that ISM always replaces a cycle in the digraph with one of its member elements as a proxy for the entire cycle as soon as one is detected, and thereafter considers it as a unit substructure. In this example, the consequence of this is seen in the path connecting elements 5 and 9. In the original digraph, the direct connection is from 6 to 9; this was not

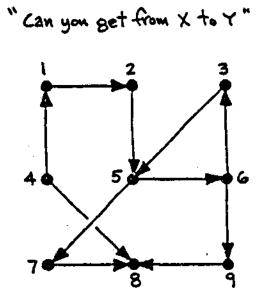


Figure B-2

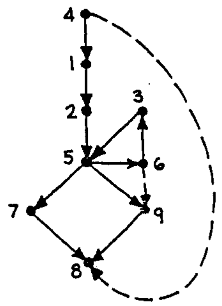


Figure B-3

ascertained in the ISM process because after the cycle (called a maximal cycle in ISM) 3-5-6-3 was detected, 5 was selected as the proxy element, and all subsequent questions were asked relative to 5.

3.) The direct path from 4 to 8 is missing in the output digraph. If the direct connection from 4 to 8 is important, then the participants will readily notice its absence during the amendment process and it will be added. Similarly, to the extent that the direct connection from 6 to 9 is important, rather than going through 5, the participants will "notice" this (with the help of the facilitator), and include the extra path. These are indicated as dotted lines in Fig. B-3.

Two suggestions for the facilitator result:

1) After the participants get a chance to study the output digraph, prod them to look for "missing links", and

2) Prod the participants to look for links with elements inside a (maximal) cycle.

The particular problem chosen in Figure B-2 is a "nice" one in the sense of representing the kind of structure ISM is best suited to. A slight modification to Figure B-2, however, can change the situation drastically. A path is added from 8 to 1, as shown in Figure B-4. Running the same exercise using the same ISM program, results in the digraph shown in Figure B-5. Notice that there is one path shown between 4 and 1, and all the other elements are in a maximal cycle (meaning only that each element can be reached from each other element). Element 1 was chosen by the program to be the proxy for all the other elements in the cycle.

This leads us to the next topic, namely, Cycle Resolution.

2.10 Cycle Resolution

When the ISM program discovers that a number of elements can all be reached from one another, they are coalesced into a "cycle", and no further interelement processing is done relative to this subset of elements. The (maximal) cycle shown by ISM carries no information concerning the interconnections among the elements, other than that each one can be reached from any other one in the cycle.

Since ISM basically provides reachability information, ISM is not able without modification to provide a finer level of information concerning the connections among the elements in the cycle. Warfield has developed one such modification to assist the participants to "resolve" what is going on inside the cycle; he calls this cycle resolution. It consists of having the participants provide more data so more information can be imputed by ISM. This is done by asking the participants to fill out a weighted matrix for the elements of the cycle. This is called Weighted Embedding, contrasted to Transitive Embedding (which has been used in everything so far discussed). Transitive Embedding takes advantage of the transitivity property to reduce the number of questions the participant must answer. No such short cuts are available during Weighted Embedding. In this latter process, the participants must provide a number from 1 to 9 which represents the "intensity" or "importance" of the connection between each possible pairing of the elements in the cycle. Then a threshold number is selected, and the weighted matrix is converted

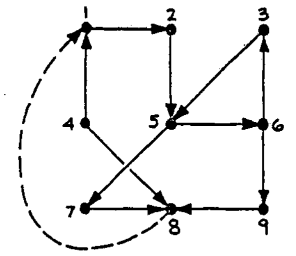


Figure B-4

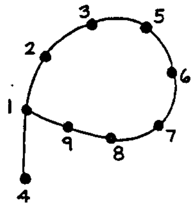


Figure B-5

to a binary matrix (since ISM requires a binary matrix). That is, a threshold number, such as 8, is selected; then a 1 is placed in each cell of the matrix where a number 8 or 9 resided, and a 0 is placed in each cell where a 1, 2,....,6, or 7 resided. There is a ("threshold") digraph map which corresponds to this binary matrix. After the threshold binary matrix is developed, the ISM programs are used to compute the corresponding reachability matrix. This new matrix is inspected to see if reachability to all the elements is preserved. If not, a different threshold (lower, in this case) is used with the weighted matrix to develop a different threshold binary matrix and its corresponding threshold digraph map (the latter now usually consists of more links). We again test for reachability; if it is not yet preserved for all elements, then the process is continued until the first threshold binary matrix is found which does so. The corresponding sequence of digraph maps is said to give some insight concerning the connections among the elements in the cycle. The participants are then asked to study the last threshold digraph map, do amending, etc., as usual in the ISM process.

A "nice", large-scale, real-world application of this procedure is described in (Fitz, 1975).

A different kind of additional insight with respect to a maximal cycles is obtainable for those cases where a maximal cycle has a number of cycle sets within it. Warfield defines Geodesic Cycles (Warfield 1976, p. 336 et seq.). The basic methodology is to compute the Geodesic Cycles, and then form a hierarchical structure of the component cycles to provide a "natural" sequence to study the cycles (the "shortest" to the "longest"). The reader is referred to Warfield's description of

the process.

As an example of the thresholding process, consider again the example stated in the previous section. To provide the "extra" date for the desired extra insight, the participants are to provide some "distance" information. In this case, ask for the participants' impression as to the "length" of the path from element X to element Y. (For this example, we can look into the "heads" of the participants by way of the digraph in Figure B-2, and directly determine the answers to this question.) The resulting distance matrix is shown in Figure B-6.

We define the thresholding operation for this example as follows: If the entry in the matrix exceeds the selected threshold value Δ, then fill in the matrix cell with a 0 (except the diagonal; always leave it 0). If the entry is equal to or less than Δ, then fill in the matrix cell with a 1. Following this, construct the corresponding digraph map. The latter is shown in Figure B-7 for a Δ of 1. Notice that for this (special?) case, the original digraph is replicated exactly, after the non-maximal cycle connections from 4 to 1 and 4 to 8 are added in. The former is obtained from the information already given by ISM (Figure B-5), and the latter during the amendment process, as per the discussion in the preceding section.

The above should, of course, be recognized as a contrived example to demonstrate certain operations. The main point is that to the extent that the participants can give insightful answers when completing the weighted matrix, additional structural insights can be gained. A point to keep in mind is that whatever is obtained in this way is more than what we started with.

	1	2	3	5	6	7	8	9
1	0	1	4	3	3	3	4	4
2	4	0	3	1	2	2	3	3
3	4	5	0	1	2	2	3	3
5	3	4	2	0	1	1	2	2
6	3	4	1	2	0	3	2	1
7	2	3	6	4	5	0	1	6
8	1	2	5	3	4	4	0	5
9	2	3	6	4	5	5	1	0

Do threshold such that
if exceed Δ, then ⇒ 0
(except diagonal)

Figure B-6

Set Δ = 1, then

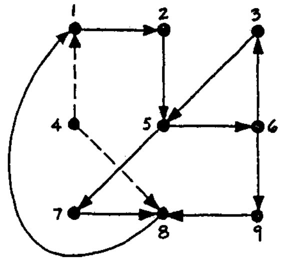


Figure B-7

Systems that demonstrate a complex cycle type of structure are likely to have associated dynamic properties that will be of interest. In these situations the users will want to develop dynamic type models. The comments of the previous section apply.

A method for going from an adjacency matrix directly to Dynamo-type model has been developed by Ulgen and Burns (1977). One is tempted to use the output of ISM directly as the input to the Ulgen-Burns methodology, BUT, the output of ISM is not precisely an adjacency matrix, so care should be taken when attempting this.

All in all, the Cycle Resolution aspect of ISM is simply an attempt to gain further insight concerning the connections among elements that are discovered to be members of a maximal cycle during the regular part of the ISM process. This further insight requires obtaining more data

from the participants. The method proposed by Warfield is that of the weighted matrix, along with a thresholding operation. A real-world example of its use is given in Fitz and Geiger. There are of course other possibilities. As one such possibility, one might use "degree-of-membership" as entries and in the weighted matrix use fuzzy set-theoretic concepts to develop a methodology for gaining additional structure insights. This is a topic for future research.

3. Concluding Comments

By and large, the users of ISM are very enthusiastic about it. It is relatively easy to use, and it does serve as a useful social tool in providing an environment for getting people of diverse views and/or backgrounds to communicate with one another, and to force the group to focus their discussion on the topic at hand. A better understanding and sharing of each other's ideas is the generally experienced result.

Though the test sessions held by the reviewers were somewhat constrained by the nature of the problem contexts contrived and/or the number of participants included, the subjective evaluation is also very positive. We feel that ISM should prove to be very useful to the TA process.

Two general comments that we would tender are:

1) ISM is clearly better than nothing, and nothing is all we have when there are a large number (say, over 30) of elements to consider.

2) Using ISM as a precurser to dynamic modeling may lead to trouble (at least without a great deal of care). In general, it is probably better to confine ISM to situations where only little feedback is expected.

Summary of ISM Characteristics*

Basic	
Maximum number of elements	~120
Computer required	Yes
Connections	
cumulative	n.a.
proportional	n.a.
functionally dependent	No
non-pairwise	No
delays	No
Vital algorithm properties	
essential assumptions	transitivity
qualitative emphasis	Yes
causal loop emphasis	No
time behavior limitations	static
Group aspects	
explicit allowance for disagreement and multiple criteria	Yes Ø
explicit group process for subjective judgments	Yes Ø
ease of use and communicability	easy

Ø Waller alternative
* For explanations of descriptors see Vol. 1, Chapter IV A.

Ease of Use of Software

Criteria for evaluating the performance of a particular interactive computer technology at the human-machine interface.

		ISM
(1)	anticipates user errors	yes
(2)	provides complete editing diagnostics	*
(3)	provides displays upon user demand	yes
(4)	multiple commands achieve the same purpose	no

* Fitz version

		ISM
(5)	operator inputs are echoed	no
(6)	easy to learn and to use	yes
(7)	provides a tutor mode for self-teaching capability	no
(8)	versatile -- easy to add new comments	no
(9)	rapid response	yes
(10)	easy to modify model	yes
(11)	easy to expand model	yes
(12)	records operator inputs for succeeding runs	yes
(13)	easy to save models	yes

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