

1997 ESSAYS ON COMPLEXITY

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PREFACE

This document is a collection of papers submitted or being prepared for submission for publication in 1997. Aggregating papers by year in this way is a new practice. In the past, each individual contribution was made available separately. This practice has become too unwieldy to manage.

The papers presented here all deal with complexity, from different perspectives. All of them are part of the conceptual underpinning for Interactive Management.

The **first paper** is intended as a platform, i.e., an intellectual base, from which to initiate sociotechnical system design. These systems are those which typically are large in scale, involve large amounts of information, involve many people and, in the past, have been very hard to design and maintain. Also they are typically not satisfactory for people who must interact with them. It proves very hard to determine the scientific basis, if any, upon which past designs have been based.

The **second paper** is intended to provide a rationale for much greater application of formalisms in integrative studies of the type typically dealt with in university education. The integrative studies could include the reorganization of individual disciplines, or the integration of existing disciplines, or the integration of existing disciplines with knowledge coming from other than academic disciplinary sources. Other types of organizations that could benefit from the use of formalisms of the type advocated here would include large consulting or contract research organizations, and governmental agencies.

The **third paper** presents the accumulated set of Laws of Complexity, developed over a prolonged period of study of complexity. These Laws are largely based in human behavior as individuals, in small groups, and in large organizations. The Laws furnish much of the scientific basis for what is offered in the first two papers.

The **fourth paper** describes the problematique, one key pattern of complexity that can be developed and applied to resolving problematic situations. The problematique is described as an extension of the syllogism, the first known discovery related to the application of inference to produce new knowledge. In support of this description, an example of a problematique is shown that incorporates 324 syllogisms, linked to one another to form an interpretive pattern of a situation believed to be complex.

The **fifth paper** is designed specifically for the bureaucrat who might be interested to read a carefully-selected set of references that have a bearing on the quality of thinking. Chosen from a bibliography with almost a thousand items, this small set of readings is tailored to issues of great complexity that are typical of those with which higher-level managers or legislators may have to cope.

The **sixth paper** is an abstract presenting a small, exclusive set of modes of representation which have met the criteria that are essential for media vehicles that profess to portray complexity.

The **final paper** describes a new index of complexity. Previously four other indexes were found, tested in applications, and reported in the literature. This new index offers a way to connect research on complexity, applications, and the history of thought about thought. An example illustrates the nature of complexity, and strives to show thereby how critical carefully designed processes are to working with complexity.

It seems likely that additional papers will be appended to this document later in the year, since it is being produced in mid-1997.

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Note: The author will appreciate comments or criticism, which can be sent to his email address: jnwarfield@aol.com. This email address is expected to continue until December of 1997. It seems likely that additional papers will be appended to this document later in the year, since it is being produced in mid-1997.

A PLATFORM FOR SOCIOTECHNICAL SYSTEM DESIGN

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Submitted to the *Journal of the Society for Design and Process Science*
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The study paper is an abstract presentation of a research project which includes a brief description of the project, the objectives, the methodology, the results, and the conclusions. It is a summary of the project and is intended to provide a quick overview of the project for those who are interested in the project.

The study paper describes a new method for the analysis of data which is based on the use of a computer. The method is described in detail and the results of the analysis are presented. The method is shown to be more efficient than the traditional method and the results are shown to be more accurate. The study paper is a valuable contribution to the field of data analysis and is a must-read for those who are interested in the field.

SOCIOTECHNICAL SYSTEM DESIGN

The study paper describes a new method for the design of sociotechnical systems. The method is based on the use of a computer and is designed to provide a more efficient and accurate design process. The method is described in detail and the results of the design are presented. The method is shown to be more efficient than the traditional method and the results are shown to be more accurate. The study paper is a valuable contribution to the field of sociotechnical system design and is a must-read for those who are interested in the field.

The study paper describes a new method for the analysis of data which is based on the use of a computer. The method is described in detail and the results of the analysis are presented. The method is shown to be more efficient than the traditional method and the results are shown to be more accurate. The study paper is a valuable contribution to the field of data analysis and is a must-read for those who are interested in the field.

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A PLATFORM FOR SOCIOTECHNICAL SYSTEM DESIGN

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ABSTRACT

News reports about billion-dollar debacles in large system design are becoming commonplace. It is evident that the prevailing ways of designing those large systems that depend on both technology and people as key components (the sociotechnical systems) are unsatisfactory. The evidence that supports this viewpoint accumulated heavily in the nuclear industry, and now it is being augmented in large software systems.

A new platform for sociotechnical system design is presented, which is intended to reorient the system designer and system design practice. This new platform, from which sociotechnical system design activity can be confidently launched, can be described as five-dimensional. The dimensions are: human behavior, science, communication, modeling, and complexity. A basis for integrated responsiveness to the demands of these dimensions exists, accompanied by an adequate and growing body of empirical evidence of its appropriateness.

Each dimension is explored separately, then the composite, integrated reorientation is described.

A PLATFORM FOR SOCIOTECHNICAL SYSTEM DESIGN

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ABSTRACT

Now reports about technological change in large system design are becoming commonplace. It is evident that the prevailing way of thinking about large systems that depend on both technology and people as key components (the sociotechnical system) are unworkable. The evidence that supports this viewpoint is mounting heavily in the defense industry, and now it is being recognized in large enterprise systems.

A new platform for sociotechnical system design is presented, which is intended to support the system design and system design process. This new platform has which encompasses system design activities that are currently fragmented, can be described as five elements. The elements are: system behavior, system structure, system design, and complexity. A fourth element is the system design process, which is described as a sequence of activities for integrated system design. The elements of this platform are described by an abstract and a series of conceptual models of its components.

Each element is explained separately, and the platform, integrated components is described.

A PLATFORM FOR SOCIOTECHNICAL SYSTEM DESIGN

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The designer works in a conceptual space, initially with the unavailable and the uncategorized. Bearing the unshakeable cognitive burden accumulated throughout a lifetime, the designer produces and documents a system of thoughts. They must be integrated into a creative, disciplined framework in which the details appear in context. The design must be faithfully communicable to transformation agents, who convert the designer's conceptual product into a functioning system in the world of action.

What the designer produces, and whether it succeeds or fails, may depend strongly on the orientation with which the designer initiates, plans, and steers the design activity. The designer's orientation system is a platform from which design work is launched. Its nature should be visible.

The **sociotechnical system** designer faces an extreme version of the orientation challenge. In many ordinary design situations, the designer can call on experience with predecessor designs to form the nucleus of the upgraded design. But the sociotechnical system designer is often responsible for spawning a one-of-a-kind creation. If the new design is to replace an existing system, it is almost certainly true that no identifiable design history is available; only a record of intermittent troubles. An overview of a problematic situation is demanded, from which an accurate diagnosis showing what is to be remedied can be conceived.

A standard orienting platform that can be applied by sociotechnical system designers to initiate, plan, and launch design programs for large systems is essential. It can provide a useful starting framework in any particular instance. It can provide a basis for professional development of system designers in all design fields. It can constitute an oasis in the prevailing system design desert.

The possibility of creating such an orientation can be enhanced if its platform is rooted in extensive study and integration of various topical areas of research from the past. That type of platform is precisely what is offered here.

It is viewed as a five-dimensional structure, organized under these dimensions:

- **Behavior**
 - of individuals acting alone
 - of individuals acting in a design group
 - of individuals acting in an organization
- **Science**
 - as the principal means of accumulating high-quality knowledge
 - as the basis for enhancing and upgrading intuitive designs
 - as the key to comprehending complexity
- **Communication**
 - about design, in organizations
 - inhibited by inappropriate media
 - assisted by skillful use of formalisms
- **Modeling**
 - as critically sensitive to language and careful definition
 - as founded in structural concepts, illustrated by examples
 - as a generic activity, with a wide variety of modes and types
- **Complexity**
 - clarified through the philosophy of C. S. Peirce
 - quantified through several metrics
 - seen in overview

The platform is based on 30 years of research into complexity. The research has yielded 20 Laws of Complexity that are very relevant to system design. These Laws are categorized. A majority of them (70%) fall in the Behavioral category (Warfield, 1997). Our discussion begins with human behavior.

1. HUMAN BEHAVIOR

This is not the place to discuss the **good** features of human behavior in any detail. Those features make sociotechnical system design possible. It is the other features that we have to come to grips with: those bad features that have to be overcome to get high-quality designs.

Some features of human behavior identifiable as contributors to the development of bad systems are:

- **Unwarranted Acceptance.** A propensity to accept unquestioningly (a) prevailing system design practice (in the face of ample evidence of its frequent inadequacy) and (b) assertions of authority figures or experts or representatives of "prestigious" institutions as appropriate to design practice.

- **Insensitivity to Scale.** Insensitivity to scale, transferring practices from very small-scale situations to very large situations, without recognizing that practices may not "scale up". Ability to design a model airplane from balsa is not sufficient to design a wide-body jet airplane.
- **Imbalance in Attention to Human Aspects of a Situation.** Technologists often limit severely consideration of human aspects of a situation in design practices. The idea that "human factors" represent an adequate knowledge base, as currently practiced, is far too simplistic.
- **Adhocracy in Process.** Design processes are too frequently ad hoc. Individuals who would never choose people at random to fly their commercial airplanes, or to prepare their food, see no problem in letting design processes emerge where they will. Individuals who would be unlikely to go into battle without basic training see no problem in "bringing new people on board for on-the-job training" in large-scale design situations. Universities suggest silently by examples that the way to learn to design is to solve large numbers of small-scale problems of analysis, using predetermined quantitative algorithms, offered as legitimate.
- **Unspoken Assumptions.** Managers usually operate from unspoken, untested (often subliminal) assumptions which, if aired and discussed in broadly-based forums, would stimulate discussion that would show the assumptions to be unsatisfactory. The platform offered here unobtrusively, but unrelentingly, eliminates such behavior through quality control of design process.

The new platform incorporates behavioral knowledge available from research investigations. A sharp distinction is made between human behavior in (a) an individual work mode, (b) groups, and (c) larger organizations. Absent clear evidence to the contrary, it is safe to assume that any particular individual's behavior will vary dramatically depending upon the context. This is such an important matter that we emphasize it by defining three contexts for individual behavior:

- **Context 1.** The Individual Working Alone
- **Context 2.** The Individual Working in a Group
- **Context 3.** The Individual Working in a Large Organization

Limitations and idiosyncracies are distinct in these various contexts, as are the opportunities that vary from one context to another.

In **Context 1**, The Individual Working Alone, the individual can make decisions without delay. Sometimes that is a vital asset. In large-system design, it is a hazard. Research demonstrates severe human limitations in processing information (Miller, 1956; Simon, 1974; Warfield, 1988)

which explain why certain critical relationships having a bearing on success will go unrecognized. Individuals differ in the types of knowledge they possess.

Context 2, The Individual Working in a Group, supports the elicitation of knowledge from a variety of people. When complexity is present, it also ensures that people will disagree on relative importance of ideas (Warfield, 1995). Groups will succumb to pressure to make decisions, and will recommend ideas that none of the individual members of the group consider satisfactory (Janis, 1982a,b; Warfield and Teigen, 1993). Leaders who are unaware of the documented perils of groupthink are quite vulnerable to getting and accepting bad recommendations from groups. Leaders are responsible for pressuring groups into a position where they find it appropriate to render bad recommendations as consensus opinion.

Context 3, The Individual Working in a Large Organization, is of special interest at implementation time. Organizations exist in order to make possible outcomes that cannot be had by individuals acting alone, or by small groups working without the capabilities and resources of the large organization. But the chief difficulty associated with the large organization is that the critical communications flounder, causing lack of coherence and inability to implement even good designs with necessary precision.

Ad hoc design processes will not evolve into ways of behaving that stress human strengths and annul human weaknesses. The platform for sociotechnical system design includes, as a key resource, a designed and tested process for planning, managing, and implementing the system design. The platform, when followed faithfully, annuls bad behavioral features, and allocates behavioral investment among the three defined Contexts, to gain the best from each.

2. SCIENCE

The platform is founded in science. The validity of any science is readily compromised when any of four critical factors is inadequate. These factors are: the human being who contributes to the science, the language in which the science is presented, the quality of the reasoning whereby the relationships among the components of the science are hypothesized and/or justified, and the quality of the archival descriptions which, alone, make possible continuing independent evaluation and improvement by a community of scholars¹ (Goudge, 1969).

Many recently-developed bodies of knowledge are gratuitously called "sciences". Examples include computer science, information science, and management science. They cannot stand up as sciences under careful scrutiny using reasonable criteria. There is a movement at work in

¹ These four factors are called "Universal Priors to Science". They are discussed in depth in Warfield, J. N., *A Science of Generic Design: Managing Complexity Through Systems Design*, Salinas, CA: Intersystems, 1990 (two volume set); Second Edition published by Iowa State University Press, Ames, IA, 1994.

academia to diminish the influences of the physical sciences and mathematics in the curriculum² (Gross, et al, 1996). While this movement may have escaped the attention of the professional schools, it threatens the already-weak contributions of science and mathematics education as foundational ingredients of professional education. It is reinforced by misuse of the science appellation. The quality of a body of knowledge to be called a science can be assessed against these criteria:

- It is organized for referential transparency (Warfield, 1994a), making clear and distinct the foundations, the theory, the methods of the science, and their linkages (i.e., not obscuring any of the three and their linkages from independent assessment); showing illustrative examples of applications of the methods, and how the outcomes substantiate the stated foundations and theory.
- It accounts overtly for the relationship of the Universal Priors to the science, especially in its foundations.
- The Universal Priors are uniformly recognized in developing archival representations.
- Representations of the science (if not exclusively expressed in prose) are all unambiguously translatable into (sometimes ambiguous) prose, using translation rules that are clearly presented.
- If the science has no "Laws", explanation is advanced to explain this "not-said".
- Anything that is widely accepted in the science is supported by carefully-gathered empirical evidence; and anything that is supported by empirical evidence is also justified by a carefully-reasoned explanation.
- Clear evidence of feedback channels from application arenas to the science developers is seen, and the channels are functioning well.

Perhaps the reader will strive to test one or more bodies of knowledge coming from university-based disciplines to see how these criteria are satisfied.

It is unlikely that a body of knowledge which is called a science, but which cannot meet the criteria set forth, can ever reach a pinnacle of quality. While the history of technology shows that developments in technology usually precede the development of the associated science, adhoc designs will eventually be overtaken by carefully-developed knowledge, which will be the key to reaching a high quality of system performance. Corporate

² Paul R. Gross, Norman Levitt, and Martin W. Lewis (Eds.) (1996). *The Flight from Science and Reason*, New York: Annals of The New York Academy of Sciences, Volume 775.

strategists who do not understand this place their organizations at risk. Corporate strategists who do recognize this are positioned to displace older organizations from markets, and take market share from them. The platform for sociotechnical system design incorporates, as the defining resource, a science base that points the way to high quality designs. The science incorporates operationally-defined concepts related to complexity in situations encountered in the modern world.

3. COMMUNICATION

3.1 Communication as a Source of Trouble. Faulty communication is a source of trouble in large organizations. Sociotechnical system designs invariably involve large organizations because of the scale of the situation that the system is intended to mediate. A sociotechnical system design is likely to suffer greatly if communication about the design is seen as just an overlay process on an already-existing communication framework established to support routine communication.

Because of the normal expectation that there will be heavy interactions within the ultimate designed system, the possibility of difficulties stemming from communication errors is very high. Stringent is the word to describe the issues surrounding communication in sociotechnical system design.

Newer modes of communication, with the aid of computer systems, support the need to improve accessibility among communicants. While this is commendable, there is little recognition in their designs of the necessity of diminishing cognitive burden. Many small communications may help prevent misunderstandings, but do not satisfy the critical need for large and highly-organized communication upon which the definition, quality, and understanding of a sociotechnical system design depends. Facilities to display large-scale messages for group discussion are outside the scope of present organizational practice, which stresses small displays whose size is incompatible with adequate, comprehensive communication concerning complexity. Communication media that ignore stringent requirements for communicating about many-interacting-component situations leave to the individual the unending task of correlation, integration, amendment of found errors, and development of overall comprehension; which small, uncoordinated communications cannot satisfy.

This difficulty seems to be summarized by acknowledgment that the systems are "complex", and we do not even know how to define complexity, much less how to cope with it³.

Sometimes we can draw on earlier observers for some well-expressed and critical insights.

³ For specifics, please see: George Johnson: "Researchers on Complexity Ponder What It's All About" *The New York Times*, Tuesday, May 6, 1997.

Michel Foucault was the head of a department of the history of thought at the Collège de France for about ten years. In his extensive evaluation of existing knowledge, Foucault recognized that the origins of many accepted concepts have been obscured through the passage of time. He further recognized the inadequacies in representations.

"The manifest discourse, therefore, is really no more than the repressive presence of what it does not say; and this 'not-said' is a hollow that undermines from within all that is said" (Foucault, 1993)

--M. Foucault: *The Archaeology of Knowledge*

As to how we think about the poorly-understood, we have the following incisive analysis by America's greatest native-born philosopher (Apel, 1981):

"One singular [self]-deception...which often occurs, is to mistake the sensation produced by our own unclearness of thought for a character of the object we are thinking. Instead of perceiving that the obscurity is purely subjective, we fancy that we contemplate a quality of the object which is essentially mysterious..." (Peirce, 1878).

--From: Charles Sanders Peirce (1878), "How to Make our Ideas Clear", *Popular Science Monthly* 12, 286-302.

The terms "complex system" and "complex issue" are part of the received language. Yet it is clear that Peirce considers such terms to be analogous in their usage to what economists call "externalizing your costs". The latter refers to the practice of trying to impose on other people costs inherent in the success of your own project, thereby aiming to reduce your own investment in your enterprise (e.g., build a skyscraper and let the public pay many of the consequent costs, such as the cost of access through the transportation system). If we have trouble understanding something, let's just say that it is due to undiscovered properties of whatever it is we are trying to understand. This point of view, which might be called "externalizing your limitations", relieves us of any stigma stemming from lack of understanding.

Lack of understanding is inherent in received language. Shortcomings evidenced in bad decisions by designers have arisen from the designer's uncritical acceptance of what is sometimes called "received doctrine" and "received language". The nomenclature often applied to design and other aspects of working with large systems is "problem-solving". Some systems engineers tell you that the first step in working with a large system is "problem definition". Acceptance of this nomenclature weakens the opportunity to draw out and discuss freely a "set of problems" which, when its members have been interrelated, comprise part of the description of a "problematic situation". Regularly-used concepts like "problem solving" and "problem definition" constitute **linguistic pollution**.

One of the generically-applicable products of our research is called a "problematique" (Warfield, 1996a). This structure of description involves many problems and relationships among them. It reveals many of the relationships that are at work, and gives learning opportunities that are highly-relevant to priority setting for action. We need to reserve the word problem for a well-

defined, limited use in a larger frame of thought. The idea of defining **the problem** is extremely dysfunctional, and debilitating to effective communication. That linguistic peril also implies that **the problem** will actually have a **solution**. In practice, what is usually achieved is a **workable resolution of a problematic situation**, making palatable what was previously unacceptable. The very nature of the accepted language will have a strong bearing on how design methods are assessed.

History reveals two ways to help ensure that communications are properly interpreted. One is to establish standards that become accepted in many nations. This practice accounts for world-wide ability of scientists and engineers to communicate reliably about intricate matters. Another is to ground the communications in what are called "formalisms". Formalisms are elements of formal languages which are available throughout the world as contributions of scientific investigation. While it is common practice in the software industries, for example, to create special-purpose languages, these languages are typically very defective; lacking in sound, axiomatic construction. Formalisms are kept on the back burner, which accounts for the practice of selling "shrink-wrapped" software without guarantees.

The validity of standards is closely related to prior acceptance of underlying formalisms. High-quality communication about sociotechnical systems design depends on formalisms. Philosophers explain formalisms. Formalisms are embedded in formal languages.

- **Formal Language.** *"formal language. An uninterpreted system of signs. The signs are typically of three sorts: (1) variables, for example, sentence letters p, q, r, s; (2) connectives, for example, \vee , $\&$, \neg , by which signs are joined together; and (3) punctuation devices, such as brackets, to remove ambiguity. There are also formation rules telling how to string signs together to form well-formed formulae, and transformation rules telling how to transform one string of signs into another.*
- *"Formal languages in this sense are just sets of marks permutable by rules, much as chess notation is. They may, however, be interpreted. Thus if (1) the variable letters are made to stand for propositions, (2) \vee , $\&$, \neg to stand for 'or', 'and', and 'if--then' and (3) the transformation rules are made deduction rules, then the formal language has been interpreted as a system of logic.*
- *"Distinction must be made between formal languages (uninterpreted systems of marks) and artificial languages (interpreted formal languages which are, however, not natural languages as vernacular English is)." (Flew, 1984).*

---ANTHONY FLEW (1984), *A Dictionary of Philosophy*, Revised Second Edition, New York: St. Martin's Press, 123-124.

- **Formalism.** *"formalism 1. (mathematics) A view pioneered by D. Hilbert (1862-1943) and his followers, in which it was claimed that the only foundation necessary for*

mathematics is its formalization and the proof that the system produced is consistent. Numbers (and formulae and proofs) were regarded merely as sequences of strokes, not as objects denoted by such strokes. Hilbert's programme was to put mathematics on a sound footing by reducing it (via arithmetic) to consistent axioms and derivation rules, the former being certain series of strokes, the latter ways of manipulating them. Later Gödel⁴ showed that the consistency of arithmetic cannot be proved within the system itself, thus demonstrating the impossibility of achieving part of the Hilbert programme. 2. (in ethics and aesthetics) Emphasis on formal issues at the expense of content. The term is generally employed by opponents of such attitudes." (Flew, 1984).

---ANTHONY FLEW (1984), *A Dictionary of Philosophy*, Revised 2nd Edition, New York: St. Martin's Press, 123.

While the definitions given by Flew seem thoroughly appropriate, standing alone they do not give an adequate perspective on the evolution of thinking about thought. For this purpose, we discuss seven milestones in the history of thought. These reveal a steady drift toward use of formalisms of logic that go beyond and are deeper than the more familiar computationally- and numerically-based formalisms.

3.2 Seven Milestones in the History of Thought

Many contributions to archival knowledge have been made over the centuries that are relevant to the representation of **products** of human thought (as distinguished from the biological activity involved in the process of thinking). Some contributions are of much greater significance than others, hence deserve to be called milestones. Seven milestones, linked by being mutually supportive, are highlighted here. They form part of the background for the platform.

Linkage Forms. The linkages take at least two forms. The first can be described as a linkage of a drive toward formalism; in the sense that the seven all reflect an ultimate aim to make very precise the way that the products of thought are represented. The second can be described as a linkage of dependency; because each milestone depends, in part, on enlightenment stemming from its temporal antecedents; and each milestone gains significance when seen in terms of its contribution to its succedents.

Time Period Involved. The elapsed period of time between the first milestone and the last is two

⁴ Gödel's work achieved an unwarranted level of capitulation that has, to a considerable extent, brought progress in the evolution of logic as a tool of learning to a screeching halt. For a discussion of this in more detail, see: J. N. Warfield, *Some Magnificent Academic Trusels and Their Social Consequences* (1992), Fairfax, VA: IASIS. In that document, a "trusel" is defined as: "an idea or finding that is widely perceived to be true, but which is largely useless (or even of negative value)". A "magnificent academic trusel" (e.g., Gödel's Theorem) is defined as "one that has been widely acknowledged for its intellectual content (explicitly or implicitly), but without a corresponding amount of attention being given to its utility or even to its potential negative value for society".

and one-half millennia.

The Milestones Tabulated. Here is the tabulation of the seven milestones.

- *Milestone 1. Aristotle's Articulation of Categories and Syllogisms.* (Aristotle, **Fourth Century, B. C.**) (Aristotle, 1983).
- *Milestone 2. Abélard's Articulation of (but not naming of) Transitivity, Antecedents, and Succedents.* **Twelfth Century, A. D.** (Bochenski, 1970).
- *Milestone 3. Leibniz's Introduction of Graphical Symbolism to Portray Reasoning Patterns.* **Eighteenth Century, A. D.** (Bochenski, 1970).
- *Milestone 4. Boole's Propositional Calculus and De Morgan's Theory of Relations,* **Nineteenth Century, A. D.** (Coupled for two reasons: the key publications came in the same year, 1847; and Boole credited De Morgan as a source of inspiration. Both authors were English) (Bochenski, 1970).
- *Milestone 5. C. S. Peirce's Connection of Logic to Science in General,* incorporating his recognition of De Morgan's Theory of Relations, his popularization of the importance of transitivity, his discovery of the necessity and sufficiency of triadic relations to articulate all relationships, and his clarification of flaws in previous philosophical writings. **Nineteenth Century, extending into the Twentieth** (Brent, 1993).
- *Milestone 6. Harary's Development of Linkages among Branches of Mathematics,* in which he establishes permanently the connection between formalisms of the logic of propositions, and graphical representations as digraphs. (**Twentieth Century**) (Harary, et al, 1965).
- *Milestone 7. Articulation of Interpretive Structural Modeling (ISM)* (as the means of applying Harary's analytical mathematics to the computer-assisted synthesis of structural models). **Twentieth Century, 1974**)⁵.

Connecting the End Milestones. *Milestones 1 and 7* (the "end milestones") are connected via the fact that every Interpretive Structural Model is an array of linked syllogisms. The use of software to produce interpretive structural models enables groups of people to create and link syllogisms into consistent logic patterns. This capacity represents the formalism underlying all representations of relationships and is, therefore, fundamental.

⁵ In Warfield's *Structuring Complex Systems*, Columbus: Battelle Memorial Institute Monograph No. 4, April, 1974; and later elaborated in his *Societal Systems: Planning, Policy, and Complexity*, New York: Wiley, 1976 (reprinted, 1989, Seaside, CA: Intersystems; out of print, available from UMI, Inc., Ann Arbor, MI).

- **Milestone 2 Contribution.** The contribution of *Milestone 2* is to articulate initially the significance of transitivity and of antecedent and succedent concepts, furnishing the statements which, when replaced in a one-to-one way with symbols, fit perfectly into De Morgan's Theory of Relations, providing the formal basis for Harary's focus upon transitive relations.
- **Milestone 3 Contribution.** *Milestone 3* reflects the introduction of elementary geometric portrayals into logic visualization and interpretation of representation.
- **Milestone 4 Key Formalisms.** *Milestone 4* provided the formalisms needed to construct relational statements, and to apply the formalities of Boolean algebra to their manipulation and organization.
- **Integrative Insights.** *Milestone 5* put everything into perspective, facilitating the interpretation of previous and future developments in a way consistent with the best view of scientific thinking; divorcing such developments from incorrect thinking propagated by adherents to originating philosophers such as Bacon, Comte, Descartes, Habermas, both Mills, and others. *Milestone 6* placed the integrative insights into formalisms, making them operationally useful.

Conclusions About the History of Thought. What key conclusions can be drawn that reflect the seven Milestones?

- **Drift Toward Formalism.** First we can see the drift toward formalism, occurring over a period of more than two millennia.
- **Enabling Applications.** We can reflect on how this drift toward formalism has slowly established the basis for computer help in organizing collaboratively-constructed products of human thought in forms suitable for effective communication.
- **Pervasive Neglect.** We can observe the pervasive neglect of these seven milestones in today's educational system, which remains largely content to work with ideologically-based language (in spite of the power made available through these milestones); and which largely fails to make these milestones known to the students or relevant external constituencies.
- **Breadth of Application.** Because of the outstanding work already done and continuing to be done by practitioners of Interactive Management (IM)⁶ (Warfield and Cárdenas,

⁶ Interactive Management (IM) is a system of management developed specifically to enable organizations to cope with complexity. One of its distinguishing features is its heavy reliance on Interpretive Structural Modeling (ISM) to help groups organize their collective knowledge. It is described in John N. Warfield and A. Roxana Cárdenas (1994), *A Handbook of Interactive Management*, Ames, IA: The Iowa State University Press.

1994), the astonishing breadth of application of ISM is becoming steadily more evident.

- **The Battle for Attention.** Particularly in the realm of organizational activity; the high consulting fees being obtained by today's high-visibility management gurus, and the high stakes involved in promoting alternative concepts of complexity, together make clear that there is a battle for attention in application communities (Jackson, 1995). If visibility is the main criterion to judge who is winning this battle, it seems clear that IM is losing the battle and that concepts espoused by high-profile management gurus are carrying the day.
- **Documented Results.** But if concrete results and clear documentation⁷ of them and their benefits is taken as the main criterion, it seems clear that the wisdom found in the seven milestones is winning the battle and that, over time, even the universities will have to take note and begin to reshape their operations accordingly (although a few are already involved with IM).

3.3 A Shared Linguistic Domain

Maturana and Varela have stressed the critical importance of a shared linguistic domain to effective communication. When the object of the communication is to construct and implement a sociotechnical system, the criticality is at a peak. The construction of such a domain is part of the challenge facing the participants in the design and implementation activity. These key definitions are relevant to the platform.

- *Definition by NAMING* (normally of value only by focusing attention on shortcomings of understanding)
- *Definition by INTENSION* (by enumerating the attributes of the object of our attention; works better when the object is observable, rather than a category)
- *Definition by EXTENSION* (enumerating "for instances"; works better when the object is a category)
- *Definition by RELATIONSHIPS* (the highest standard, seldom applied to problematic situations, where it is most needed)
- *Description exclusively by PROSE* (restricted to linear, linguistic modeling)
- *Description by TRUNCATED-PROSE GRAPHIC* (typical of technological descriptions,

⁷ An 80-page annotated bibliography is available on the Internet at this URL:
http://www.statewave.com/tiers_1_4/BIBWARF.htm. This is available courtesy of Statewave, an organization in Florida. Other related material is available at the following location:
<http://www.gmu.edu/departments/tipp/faculty/warfield/warfield.htm>.

leaving too much to the imagination)

- *Description by HYBRID STRUCTURE* (striving to take maximum advantage of combined prose-graphics representation, allowing both hierarchical and cyclic structural components)
- *Definition of PROBLEM*: A problem is an authored statement which (a) describes something that is significantly annoying to its author, and (b) does not require reduction into lesser statements in order to be understood.
- *Definition of SYSTEM*: A system is: "Any portion of the material universe which we choose to separate in thought from the rest of the universe, for the purpose of considering and discussing the various changes which may occur within it under various conditions" (Rukeyser, 1942; from J. Willard Gibbs).
- *Definition of KNOWLEDGE*: Knowledge refers to belief that (a) has been depersonalized; i.e., no longer derives its interpretation solely by reference to its formulation by the original believer, (b) has achieved acceptance by a definable body of believers, and (c) may have become detached from whatever gave it its original credibility. [Much of what is now regarded as knowledge is being challenged by the "deconstructionists".]
- *Definition of VALID KNOWLEDGE*: Valid knowledge is knowledge that is regularly re-evaluated by dedicated scholars and which, at a given time, has yet to be shown to be defective. [The fact that some valid knowledge may at a later time be shown to be defective is irrelevant to its current classification.]

No problematic situation involving complexity can be accurately described, diagnosed, and represented to others in the absence of a shared linguistic domain. Any high-quality shared linguistic domain will necessarily rely on some arbitrary set of definitions for its integrity. The platform requires such a domain, and those who wish to share it are required to accept such an arbitrary set, to satisfy the requirements of communication. Those who find the arbitrary set presented here unsatisfactory may choose to reject it, but they should not choose to ignore the requirement. So if they reject the set given here, the responsible strategy would be to create a competing set, and offer that to persons interested in the design of sociotechnical systems.

The platform incorporates the given set, in its foundations.

The use of formalisms coming from formal languages appears, on the one hand, to be essential as a means of quality control on communication. Theorists and practitioners alike realize that such formalisms cannot normally be part of a widely-shared linguistic domain. There are basically two ways to adapt to these seemingly incompatible conditions. One way is to hide the formalisms from general view, and replace them in the shared linguistic domain with a set of metaphors tailored to enhance acceptance. The other way is to make the formalisms available to

application communities by creating computer software that places the formalisms at the service of that community, without requiring that the community become familiar with specifics of the formalisms, but requiring only that they value the services that can be provided to the practitioner community.

If the first route is taken, authors are likely to take many liberties, such as those described in Section 1.0. The second route is the one that is followed in the platform.

4. MODELING

"Modeling", as used here is seen in a very general context, to mean the formulation by people of any type of recognizable conceptual construction (Warfield, 1994b). With this broad understanding, we must somehow narrow the scope of our discourse to that which is directly relevant to sociotechnical system design. We have already indicated that formalisms are critical components of that activity. We shall then restrict the discussion of modeling to those activities that use formalisms. Even this restriction is not heavily binding, and it will be necessary to zero in still more. But since almost all formalisms originate in mathematics, we may first look at mathematicians to see whether some categories are available to help us in dealing with modeling. One classification of mathematical minds identified three leading classes (Rukeyser, 1942):

- "**the logicians**, whose pleasure and power lies in the subtlety (sic) of definition and dialectic skill",
- "**the geometers**, whose power lies in the use of the space-intuitions"; and
- "**the formalists**, who seek to find an algorithm for every operation"

We may take advantage of these categories to make some critical distinctions. Most of the modeling that goes on in the applied systems arenas is a curious mix of geometrical and formalistic modeling, which buries the logic aspects entirely. Traditionally in engineering some form of geometric modeling has been essential. Also the use of algorithms (i.e., typically mathematical recipes for computations) is commonplace. The logical underpinnings of the hybrid geometric-formalist practices can lend great credibility to modeling, but only if spelled out; not when "not-said".

The most powerful modeling scheme is one that skilfully integrates the best features of all three of these classes. Unfortunately, territorial self-selection normally assures that there will no such integration. That is why the Harary product, described in Section 3.0 as one of the seven milestones, is so unique. It incorporates integrated components from all three categories. Of the three categories, the logical is the most fundamental, requiring the most attention to knowledge organization. The geometric and algorithmic categories are the most amenable to disjointed use. It is only when all three categories are properly integrated that the geometric and algorithmic categories reach the pinnacle of their utility.

In terms of model utility, we can be informed by the comments of Dr. Thomas Lee who, during his tenure as Director of the International Institute for Applied System Analysis in Laxenburg, Austria, authorized a study of modeling practice by a president of a forest products company. Following the conclusion of this year-long effort, Dr. Lee and two co-authors⁸ summarized the results as follows:

- *What We Typically Get.* What we typically get from modelers are very sophisticated models, based on very simplistic assumptions.
- *What We Typically Need.* What we typically need are very simple models, based upon very sophisticated assumptions.

The following paragraph summarizes the basic nature of modeling. Figure 1 shows the types of models referred to in this description. Figure 1 emphasizes the nonlinear structural model type.

All human knowledge is constructed by human beings (consciously or unconsciously) as collections of models, formal, informal, or hybrid (a mixture of formal and informal). Formal models are numerant, structural, or hybrid (a mixture of numerant and structural). Structural models are linear or non-linear. A linear structural model is isomorphic to a directed graph--a directed line can be passed through all vertexes and lines without touching any more than once.

If an arrow or sequence of arrows is directed from a lower-level element to a higher-level element in Figure 1, it means that the former is included in the latter, as indicated by the description to the right of the defining arrow. The highlighted items form a prose chain equivalent, which reads: "(The type) Nonlinear Formal Structural Model is included in (The type) Structural Formal Model, which is included in (The type) Formal Model, which is included in (The type) Model."

In modeling practice, one typically finds "numerant formal models" of a very sophisticated nature, based on very simplistic assumptions. The nonlinear formal structural models, when properly constructed, can be interpreted as very sophisticated assumptions, from which simple prose models can be constructed, following interpretation procedures given elsewhere. Examples of nonlinear formal structural models will be discussed later in this paper. Not only can these models be viewed as sophisticated assumptions, but they can provide the usually-absent logical rationale and direction for developing numerant models, whenever they are clearly required.

Modelers seldom avail themselves of the full set of possibilities. Instead they typically construct models based on undue acceptance of received doctrine. They emulate past modeling work, and thereby incorporate in their models all of the traditional, prototypical

⁸ T. H. Lee, B. C. Balil, and R. D. Tabors (1990), *Energy Aftermath*, Boston: Harvard Business School Press (ISBN: 0875842194).

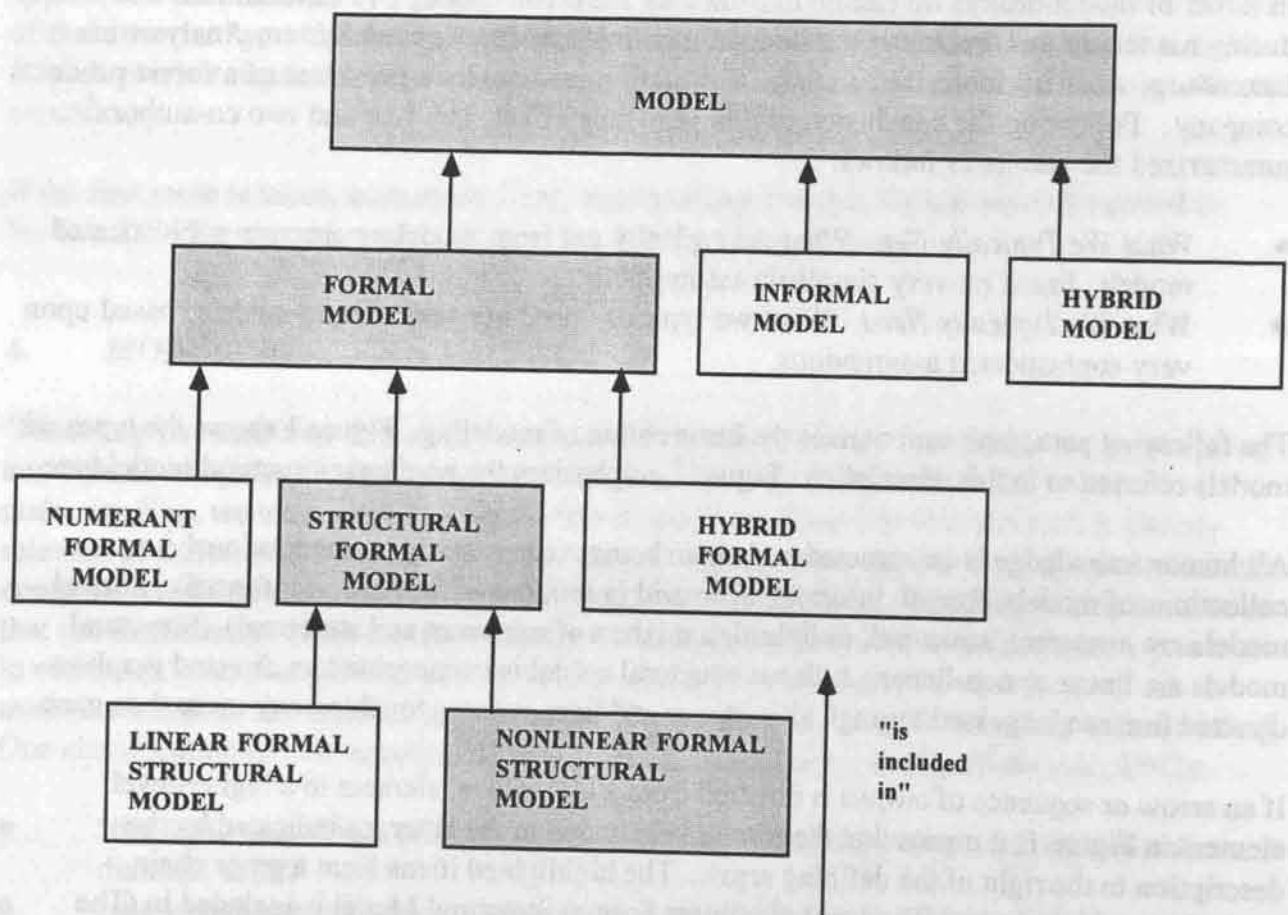


Figure 1. HIERARCHY OF MODEL TYPES WITH EMPHASIS ON NONLINEAR FORMAL STRUCTURAL MODEL TYPE

fundamental mistakes in previous work. Such models get translated into costly and dysfunctional outcomes in organizations. Such practices are unacceptable in the platform, which supports and enables the changes required to reinvigorate modeling practice.

5. COMPLEXITY

Complexity imposes dominating conditions for success in designing large sociotechnical systems. If these conditions are ignored, as they usually are, failure is virtually ensured. It is absolutely critical to understand the nature of complexity and the demands imposed by complexity, in order to become competent in sociotechnical system design. Unfortunately new schools of thought are being set forth that threaten to prolong the agony associated with efforts to overcome complexity. So our discussion of complexity must begin by reviewing the various schools of thought. Table 1 presents an overview of the five schools that can be identified now.

These five schools are discussed in cited references⁹.

TABLE 1. SCHOOLS OF THOUGHT ABOUT COMPLEXITY		
NAME OF SCHOOL	UNDERLYING FORMALISM	WHERE COMPLEXITY IS SAID TO LIE
Cross-discipline	None (Prose, even when compelling, is not a formalism)	Unspecified
Systems Dynamics	Ordinary differential equations	In the system
Chaos Theory	Ordinary nonlinear differential equations	In the system
Adaptive Systems Theory	Partial differential equations	In the system
Structure-based	Formal western logic, including set theory, theory of relations, digraph theory, lattice theory, boolean methods, and the algebra of partitions	In the mind [Much of the foundational thinking is represented by the works of Peirce, Piaget, Polanyi, and Vickers.]

The following brief descriptions will identify them for those persons who are presently aware of their nature:

- The cross-discipline or interdisciplinary "approaches" or "methods" are fostered by the Association for Integrative Studies: a predominantly liberal-arts, small-college-faculty activity, with good leadership, dedicated to integrative activity, but lacking adequate apparatus to work with complexity
- Systems dynamics fostered by Jay Forrester, Dennis Meadows, Peter Senge, and others closely associated with the Massachusetts Institute of Technology [the late 20th century successor to the French Ecole Polytechnique, where positivism was born, as so insightfully made clear (Hayek, 1955)]
- Chaos theory (arising in small groups in many locations, and threatening to make dubious metaphors displace careful analysis and design, in education and in practice)
- Adaptive systems theory (predominantly associated with the Santa Fe Institute, which has

⁹ Scheduled for publication in 1997, a magnificent work by Charles François titled *Encyclopedia of General Systems and Cybernetics* will allow many comparisons to be made among these schools, providing many references and insightful commentary.

commandeered the word "complexity" without any clear concern for the downgrading of scope of the term and the diminution of its utility in science)

- The Structure-Based school (developed by the author, his colleagues and associates following the slow drift toward formalism identified in the seven milestones)

5.1 Findings of the Structure-Based School

The Structure-Based School is responsible for significant advances in comprehending complexity, and demonstrating how to work with it from a broad scientific, philosophical, and empirical perspective.

The studies of this School show that situations viewed as complex share these three definitive features:

- A plethora of component problems
- Widespread differences of belief (Spreadthink; Warfield, 1995)
- A large number of problem interdependencies

In a typical project involving complexity, using well-defined group processes, it is common that many component problems relevant to the problematic situation are identified and clarified, each problem being one facet of the system under study. Individualized voting by members of the group inevitably reveals different beliefs among members about the relative importance of problems involved in the system being studied. (This pervasive condition has since been titled "Spreadthink") (Warfield, 1995). Finally, the many interdependencies among the problems are revealed by developing, in a facilitated, computer-assisted group process the formal nonlinear structural model called a "problematique". The latter shows the interdependencies, and the pattern of their interdependence. [Section 5.0 shows examples.]

Many projects of the type just mentioned have made it possible to describe the following aspects of complexity, which are integrated in the platform for sociotechnical system design:

- Twenty Laws of Complexity (Warfield, 1997)
- Seven Ways to Represent Complexity (Warfield, 1994a, Warfield and Cárdenas, 1994)
- Five Numerical Indexes of Complexity, with Applications Data (Staley, 1995)
- A Communications Hierarchy, Called the Alberts Pattern (Alberts, 1995)
- A Corresponding Three-Level Hierarchy of Organizational Communication About Design Options in a Problematic Situation, called the Cárdenas-Rivas Pattern, whose 3-level structure correlates closely with that of the Alberts Pattern (Cárdenas and Rivas, 1995)
- An Infrastructural Arrangement Required for Effective Organizational Learning About the Problematic Situation, Called the Corporate Observatory (Warfield, 1996b)
- A Comprehensive Definition of Complexity (Warfield, 1996c)
- The Behavior-Outcomes Matrix, with Various Fills, Summarizing the Findings

Any one of these outcomes could occupy far too much space to be encompassed here. References are available to add breadth and depth to make them understandable. We have introduced the components of the platform. Before presenting it, representative problematques will be described, which should help to make the description of the platform easier to follow.

5.2 The JOPES Problematiques

The problematic situation involved in developing the JOPES Problematiques is part of the larger situation facing the U. S. Department of Defense as a consequence of the end of the Cold War, accompanied by the many local conflicts that have burst into prominence in the past decade. Greatly enhanced world-wide communication has raised visions and expectations that dictators and heavy-handed governments are unable to satisfy. JOPES is an acronym for Joint Planning and Execution Process. Figure 2 shows a Problematique for the JOPES Problem Categories only. This was derived from the larger JOPES Problematique for Problems, Figure 3.

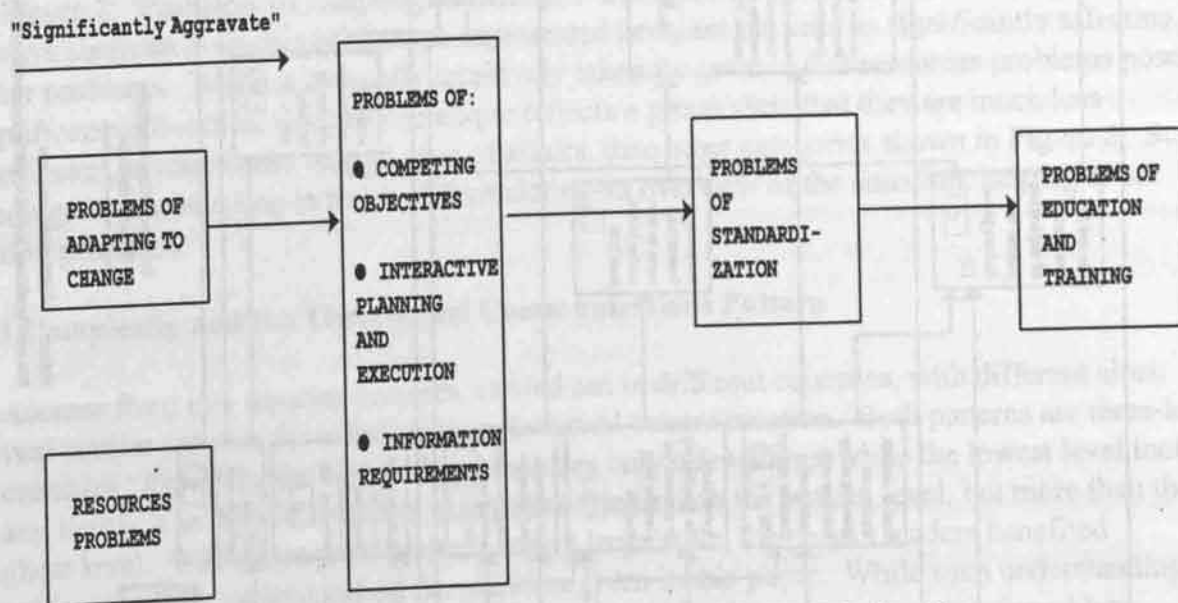


Figure 2. JOPES Problematique for Problem Categories (only)
[Problematique for Problems appears in Figure 3]

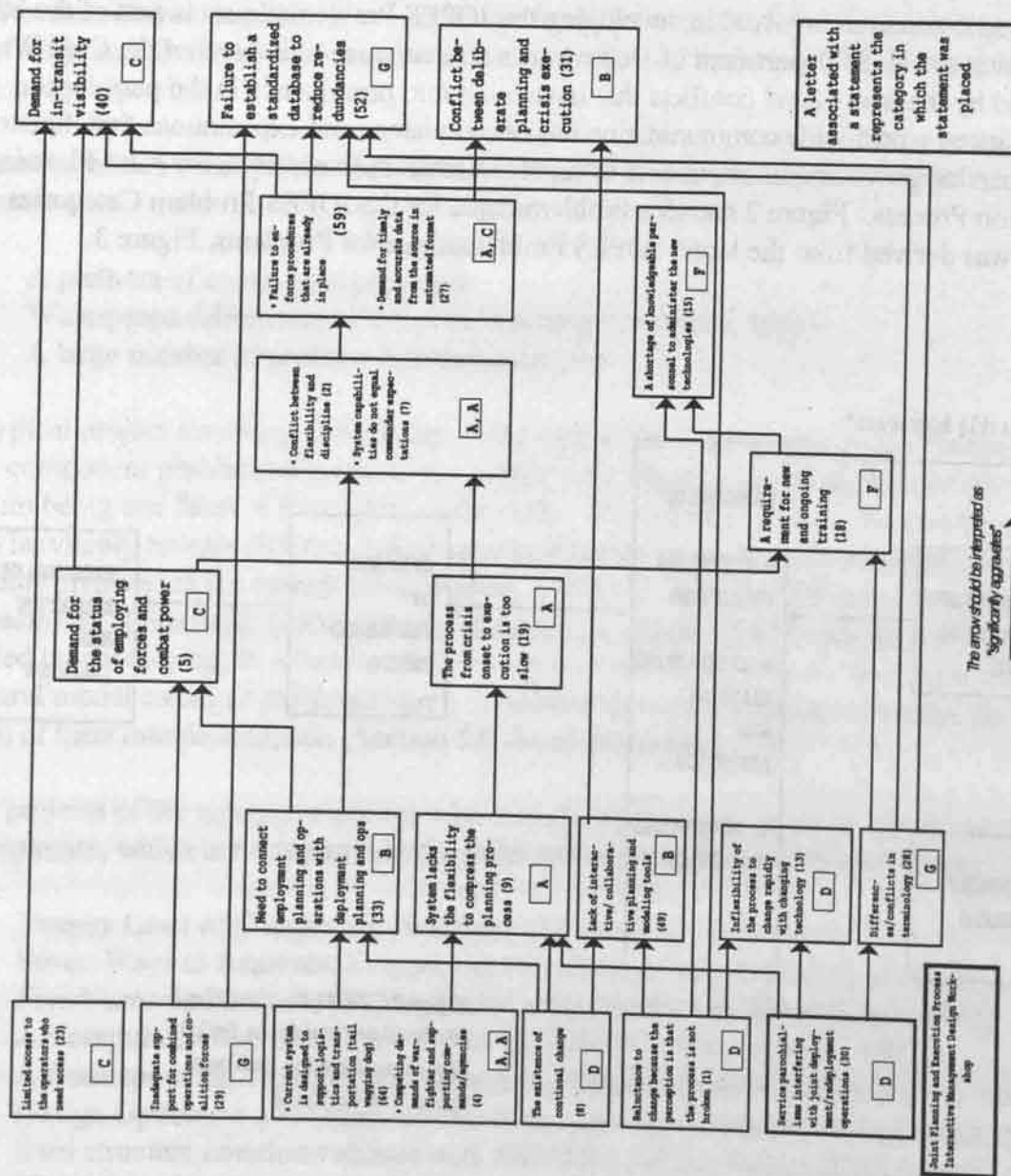


Figure 3. JOPES Problematics
How some problems significantly aggravate others

The JOPEs Problematique shown in Figure 3 was developed in a facilitated group process, with assistance from Interpretive Structural Modeling software. Capital letters in Figure 3 correspond to the categories in which the problems lie.

The drawing in Figure 3 shows how some problems significantly aggravate (make more severe) other problems. In a separate group session, also facilitated with help from the same computer software, the problems were placed in seven categories, which were given distinctive titles based on the problems contained in them. By noting the relationships among categories which can be derived directly from Figure 3, it is possible to construct manually the smaller problematique shown in Figure 2. It is good practice to write a detailed interpretation of the problematiques for purposes of helping make sure that the structure, once completed, appears not to require amendment. This type of concern should always be honored, since much of the structure is based on computer inferences calculated from information supplied by the participants. The use of inference saves many hours of expensive group work; and only a small percentage of the time saved is required to test the written interpretation and amend it, if required.

In Figure 2, the Problem Category that affects all other Problem Categories is the leftmost item in Figure 2: "Problems of Adapting to Change". In Figure 2, "Resources Problems", while always surfaced in studies of the type represented here, are not seen as significantly affecting any other problems. While it is usually intuitively taken for granted that resources problems pose significant difficulties; this problematique reflects a group view that they are much less significant, at least in the current state of affairs, than other categories shown in Figure 2. Such findings are outstanding in terms of formulating an overview of the situation, helping to set action priorities.

5.3 Complexity and the Three-Level Communications Pattern

Outcomes from two separate projects, carried out in different countries, with different aims, reveal similar patterns for effective organizational communication. Both patterns are three-level hierarchies. For each, the highest level includes only a few items, while the lowest level includes many items. The middle level has many fewer items than the bottom level, but more than the highest level. While these two projects reflect large scale, the project leaders benefited significantly from understanding the platform given in this paper. While such understanding is far from widespread in practice, it is well-represented by the two projects mentioned here.

Table 2 summarizes the relevant data. The first data row in Table 2 is assigned to a project aimed at redesigning the U. S. Defense Acquisition System (Alberts, 1995). This project, under the leadership of Professor Henry C. Alberts of the Defense Systems Management College, Fort Belvoir, Virginia, included as participants over 300 officially-designated program managers and a few Congressional staff attorneys, who worked intermittently during the five-year conduct of the system redesign. These program managers identified 678 problems with the existing system (a system that had evolved in an ad hoc way over many years). Ultimately they were able to place these problems into 20 un-named categories. Once the problems had been categorized,

names were given to the categories. Then the 20 problem categories were placed into 6 problem areas or domains, and the areas were named in the light of the categories they contained. This produced a 3-level hierarchy, which is called a "communications hierarchy", because in order to resolve the problems, cooperation among the people working at each level is essential. The three levels were given the names that are commonly applied in long-range planning: strategic (the highest level), tactical (the next highest level) and operational (the lowest level, where day-to-day encounters with the problems form much of the experience of the program managers). The work done in this project ultimately contributed to Congressional passage of an acquisition streamlining act in 1994. In recognition of his contribution, Professor Alberts was awarded the George Mason Medal by George Mason University.

Some time later, at a highly-respected institution in Mexico, known by the acronym ITESM, a project was jointly carried out by Professors Roxana Cárdenas and Jose Rivas (Cardenas and Rivas, 1995). The project was done as part of a class design project, largely by advanced students, who worked to redesign their educational program in the light of their experience with the program. While they also uncovered problems, they matched the problems with design options. They arrived independently of Professor Alberts' work at a similar structure for the design options. They found 270 design options, which ultimately were located in 20 options categories and the latter, in turn, were placed into 4 option domains. There is a clear correlation between the two structures. It seems reasonable to hypothesize that such structures could be found in most large organizations, by working in the design mode corresponding to the platform presented here.

Table 2. COMMUNICATION PATTERNS IN ORGANIZATIONS

ORGANIZATION (and Product)	NUMBER OF ELEMENTS Lowest (Operational) Level	NUMBER OF ELEMENT CATEGORIES Middle (Tactical) Level	NUMBER OF ELEMENT DOMAINS Highest (Strategic) Level
U. S. Defense Acquisition System Redesign (The Alberts Pattern)	678 problems	20 problem categories	6 problem domains
Instituto Tecnológico y de Estudios Superiores de Monterrey- Industrial and Systems Engineering Dept. Curriculum Redesign (The Cárdenas-Rivas Pattern)	270 design options	20 design option categories	4 design option domains

The development of these patterns was accompanied by development of several structural model types, which informed the production of the results appearing in Table 2.

6. THE PLATFORM

In the foregoing, a background has been outlined to help in presenting the description of the Platform for Sociotechnical System Design. It incorporates a strong belief that cognitive viability is the most essential foundation for the platform. Cognitive viability demands that the following criteria for cognitive viability hold for the problematic situation (call it X):

- C1. X can be thoroughly articulated.
- C2. As a consequence of C1, X is learnable and what is learned is credible.
- C3. As a consequence of C1 and C2, a remedial design for X can be achieved and applied effectively.

The summary tabular outline (the "template") for the platform is the Behavior-Outcomes Matrix. The matrix is bordered by two sets. Behavioral concerns form the vertical index set. Outcomes sought form the horizontal index set. The four outcomes are called "The Work Program of Complexity". To form a particular manifestation (a version) of this template matrix, entries can be placed in the several cells to illustrate features at the intersection of a behavioral and an outcome component. In a frequently-used version the cells show the names of those Laws of Complexity that are highly relevant to that particular cell. Other versions can show, e.g., which of the seven ways of portraying complexity are especially relevant to that cell, in the light of empirical evidence accumulated over many years.

Figure 4 illustrates one version of the Behavior-Outcomes Matrix. This is the one mentioned above, in which names of Laws of Complexity appear in the cells.

The Laws of Complexity are categorized as follows (with a few placed in more than one category):

Type A. Three Categories Involving Human Behavior (14 of the 20 Laws):

- **Habitual Behavior (7 of the 20 Laws):** Constraints that human beings have imposed upon themselves, almost without thinking, evolved through prolonged activity
- **Physiological Behavior (5 of the 20 Laws):** Constraints on human behavior imposed by their physiology
- **Organizational Behavior (5 of the 20 Laws):** Aspects of human behavior that involve their participation in organizations

Type B. A Category Involving Linguistics of Communication (2 of the 20 Laws):

Matters that affect media of human communication, including various aspects of human written or oral interactions

Type C. A Category Involving Mathematical Determinations (6 of the 20 Laws):

Laws arrived at by mathematical operations, whether theoretical or empirically-based

		OUTCOMES			
		DESCRIPTION	DIAGNOSIS	PRESCRIPTION (DESIGN)	IMPLEMENTATION
B E H A V I O R	PROCESS	<ul style="list-style-type: none"> ■ Limits ■ Triadic Necessity & Sufficiency ■ Universal Priors 	<ul style="list-style-type: none"> ■ Success & Failure ■ Universal Priors 		<ul style="list-style-type: none"> ■ Gradation ■ Validation
	INDIVIDUAL	<ul style="list-style-type: none"> ■ Limits ■ Triadic Compatibility ■ Small Displays 		<ul style="list-style-type: none"> ■ Requisite Parsimony ■ Requisite Saliency 	
	GROUP	<ul style="list-style-type: none"> ■ Limits ■ Uncorrelated Extremes 	<ul style="list-style-type: none"> ■ Inherent Conflict ■ Structural Under-conceptualization ■ Diverse Beliefs 	<ul style="list-style-type: none"> ■ Requisite Variety ■ Induced Groupthink 	
	ORGANIZATIONAL	<ul style="list-style-type: none"> ■ Limits ■ Organizational Linguistics ■ Vertical Incoherence 	<ul style="list-style-type: none"> ■ Forced Substitution ■ Precluded Resolution ■ Vertical Incoherence 		

Figure 4. One Version of the Behavior-Outcomes Matrix, in which highly-relevant Laws of Complexity are identified for particular cells of the Matrix. The vertical index set consists of behavioral features, each of which is considered distinctly in arriving at the platform for sociotechnical system design. The horizontal index set is called The Work Program of Complexity.

In principle, a few of these laws could be abolished over time, if habitual and organizational behavioral practices were adequately changed. Unless, and until, they are, the laws will stand. Since none of the laws is based in the so-called "hard sciences", it is reasonably clear why technologists are unlikely to appreciate these laws, and are likely to believe they can dominate the territory where these laws rule.

With what has gone before, it is now easy to state the platform for sociotechnical system design.

At the outset of work, it should be assumed that there is a problematic situation, which is to be modified through a program of sociotechnical system design. This program will consist of the conduct of the Work Program of Complexity, supplemented by those actions that do not require group work, but which are informed by the products of group work. This requires that group activities be carried out sequentially (with nominal iteration within the sequence, as required). The first activity is to describe the situation. This requires the services of a group, and a management system designed to reflect the demands of complexity, called "Interactive Management". As illustrated in the two projects described briefly in Table 2, the time required will be determined by the scope of the situation, and the products required will be chosen from the seven ways to represent complexity. These are (Warfield, 1994a; Warfield and Cárdenas, 1994):

- Arrow-Bullet Diagrams (*which are mappable from square binary matrices, and which correspond to digraphs*)
- Element-Relation Diagrams (*which are mappable from incidence matrices, and which correspond to bipartite relations*)
- Fields (*which are mappable from multiple, square binary matrices, and which correspond to multiple digraphs, and which sometimes extend into tapestries*)
- Profiles (*which correspond to multiple binary vectors, and also correspond to Boolean spaces*)
- Total Inclusion Structures (*which correspond to distributive lattices and to power sets of a base set*)
- Partition Structures (*which correspond to non-distributive lattices of all partitions of a base set*)
- DELTA Charts (*which are restricted to use with temporal relationships, and which sacrifice direct mathematical connections to versatility in applications*)

Management activity will consist of phased group activity and individual activity by leaders, who support the conduct of the group activity; and who take advantage of its products to interpret and continue the work.

The diagnosis that follows the description of the problematic situation may or may not require group work, beyond that of interpreting the description. Whatever the case, following the diagnosis, group work will again be required to do the system design. Out of that work there will arise a system of action, linked to all that has been learned. This

system of action will bring into play the strength of the organization(s), with the work sequences being those that have been designed based on everything that has been learned. In order to make this succeed, it may be necessary to create an observatorium, where the products of previous work are displayed in learning sequences, at a scale that is adequate for seeing and discussing in groups, accompanied by such adjuncts (tapes, lectures, etc.) as the material to be learned requires.

7. CONCLUSION

A platform for carrying out sociotechnical system design has been outlined, and its basis in research (both theoretical and empirical) has been indicated.

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A ROLE FOR FORMALISMS IN INTEGRATIVE STUDIES

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ABSTRACT

The increasing importance of integrative studies in higher education makes it more vital to rethink integrative studies from the perspective of reaching maximum benefit. The following "substitution table" suggests that, in rethinking integrative studies, it is appropriate to subsume a number of active concepts under more embracing rubrics. Also it is noteworthy that subsumption **does not** destroy or eliminate the active concept; **does** sustain the capacity to use the active concept; and **does** provides elbow room both for perceiving that concept within the larger rubric, and for reconceptualization of the active concept within the more embracing rubric, when appropriate.

ACTIVE CONCEPT	MORE EMBRACING CONCEPT
Academic Context	Global Context
Academic Pursuits	Global Pursuits
Classroom	Learning Infrastructure
Complex System	Cognitive Shortcoming
Content	Rationalized Content, Context, and Process
Discipline	Unity
Integration of Disciplines	Integration of Knowledge
Integrative Studies	Integrative Analyses, Designs and Experiences
Knowledge	Widely Accepted, Depersonalized Belief
Problem	Problematic Situation
Prose	Combined Prose & Graphics
Received Doctrine	Integrated Knowledge Structures
Schools of Thought	Integrated Knowledge Structures
Team Teaching	Comprehensive Learning Situation
Topical Area	System

Comparison of the applicability of knowledge from a discipline with the requirements of decisionmaking in life situations is likely to reveal that knowledge from any single discipline is inadequate, by itself, to enable one to resolve a problematic situation. The span of utility of integrated knowledge stemming from a combination of several disciplines is likely to be considerably larger than that from any single discipline, if only because the larger body encompasses more than one of the smaller bodies that might be evaluated separately; assuming that the individual has the capacity to integrate and then apply the knowledge from the separate disciplines.

Consequently, integrative studies seems likely to receive a favorable evaluation when done on the basis of comparison with a single discipline. For that reason, the gradual growth of popularity of integrative studies seems likely to continue indefinitely, and to be accompanied by continuing favorable reception.

If doing better than what was done before is accepted as an evaluative criterion, one may assume that integrative studies are proving to be a success. But anyone who reads Foucault's *"The Archaeology of Knowledge"* may be brought up somewhat short, in the recognition that the same criterion has been applied for decades to the individual disciplines, because the aggregation of correlated knowledge into an accessible domain is regarded as better than the disaggregated antecedents; yet the disciplines seem to be woefully lacking in terms of applicability to problematic situations encountered in life.

The latter thought is at least one of the reasons why faculty turn to integrative studies to help fill what they perceive to be a shortcoming in higher education.

We have here the possibility that by applying the same criterion to integrative studies that was previously applied to less-than-satisfactory disciplines, the warm feeling of success may be undeservably attained by integrative studies. In any case, perhaps a more stringent criterion could be found that would better serve to assess the quality of products of integrative study and challenge the creativity of academics.

In rethinking integrative studies, it is certainly appropriate to rethink the possibility that, in developing integrative studies in higher education, we can and should draw more heavily upon guidance from selected scholarly predecessors than we appear now to be doing, whether they were academics or not. Then, this guidance can also be integrated with any relevant knowledge under exploration at present, as appropriate. The possibility of applying classical formalisms, using computer assistance (which makes those formalisms readily available, and does not require understanding of their symbolic systems as a precondition of their application) is emphasized as a key to enhancing the breadth and quality of integrative studies: especially of those that involve complexity.

Key words: formalism, integrative studies, knowledge, academia, ISM, design, complexity, productivity, problematic situation, inquiry, unity, system, model, representation, Foundations, Theory, Methodology, organization, structural thinking, technocrats

A ROLE FOR FORMALISMS IN INTEGRATIVE STUDIES

"For to say truth, whatever is very good sense must have been common sense in all times; and what we call Learning, is but the knowledge of the sense of our predecessors...I fairly confess that I have serv'd my self all I could by reading; that I made use of the judgment of authors dead and living; that I omitted no means in my power to be inform'd of my errors, both by my friends and enemies. But the true reason these pieces are not more correct, is owing to the consideration how short a time they, and I, have to live".

--- ALEXANDER POPE (1688-1744). From John Butt (Ed.), The Poems of Alexander Pope (1963), New Haven: Yale University Press.

1. IT IS AT LEAST POSSIBLE

It is at least possible that, in developing integrative studies in higher education, we can draw more heavily upon guidance from our scholarly predecessors. In this respect, I offer good assumptions and bad assumptions.

- **Bad Assumptions.** Here are some of the bad assumptions that are broadly relevant to issues pertaining to integrative studies **involving complexity** (as many inherently do).
 - **B1. Linguistic Adequacy.** That received (natural) language is adequate to present and clarify a unity¹.
 - **B2. Adequacy of Simple Amalgamation of Disciplines.** That when one academic discipline is inadequate for coping with a situation, it is only necessary to bring in representatives of two (or sometimes three or more) disciplines and this will, even in the absence of any proven integrative process, resolve the situation.
 - **B3. Sufficiency of Normal Processes for Resolving Complex Situations.** That normal processes, e.g., those taught in academia for resolving "problems" in two hours or less, can readily be exported to deal with situations much greater in scope

¹ Foucault chose the word "unities" to represent: "a number of autonomous, but not independent, domains, governed by rules, but in perpetual transformation, anonymous and without a subject, but imbuing a great many individual works" [the product of an integrative study?]

than those repeatedly dealt with in higher education. This assumption is especially prominent for processes which are quantitatively productive.

- **B4. Location of Complexity.** That complexity is located in the system under observation, i.e., the system that is the subject of the inquiry, or the topic of the lecture.

Key terminology in these assumptions will be clarified later in this paper.

- **More Bad Assumptions.** Here are additional bad assumptions that apply more narrowly, specifically to integrative technology issues, for example:

- **B5. Validity of Received Doctrine.** That received doctrine is correct or nearly so.
- **B6. Breadth of Relevance of Quantitative Formalisms.** That quantitative formalisms are almost always sufficient to provide a basis for effective action.
- **B7. Breadth of Application of Quantitative Formalisms.** That most quantitative formalisms have broad application.
- **B8. Empirical Evidence Unneeded from "Prestigious" sources.** That if received doctrine comes from "prestigious" sources it should not be challenged.

- **Enhancing the Quality of Knowledge.** If knowledge is perceived as depersonalized belief, as seems consistent with the views of Michael Polanyi² (although the concept of "personal knowledge" then becomes an oxymoron, better replaced with "personal belief", along the lines studied by C. S. Peirce), one may wish to know the origins of the beliefs that came to be part of accepted knowledge. Foucault has amply discussed matters pertaining to the inadvisability of routine acceptance of knowledge, done without regard to the origins of the beliefs and the circumstances that justified its acceptance. Earlier, F. A. Hayek sounded a very similar theme:

"The discussions of every age are filled with the issues on which its leading schools of thought differ. But the general intellectual atmosphere of the time is always determined by the views on which the opposing schools agree. They become the unspoken presuppositions of all thought, the common and unquestioningly accepted foundations on which all discussion proceeds. When we no longer share these implicit assumptions of ages long past, it is comparatively easy to recognize them. But it is different with regard to the ideas underlying the thought of more recent times."

"As Bernard Bosanquet once pointed out, 'extremes of thought may meet in error as well as in truth.' Such errors sometimes become dogmas merely because they were accepted by the different groups who quarreled on all the live issues, and may even continue to provide the tacit foundations of thought when most of the theories are forgotten which divided the thinkers to whom we owe that legacy. When this is the case, the history of ideas becomes a subject of eminently practical importance. It can help us to become aware of much that governs our own thought without our explicitly knowing it."

² M. Polanyi (1958), *Personal Knowledge*, Chicago: University of Chicago Press.

---F. A. Hayek (1955), *The Counter-Revolution of Science: Studies on the Abuse of Reason*, New York: The Free Press.

It now appears to be more necessary than ever before to look to those specific scholars whose beliefs are relevant to assessing what is acceptable today as knowledge.

This matter is particularly relevant to integrative studies, and to interdisciplinary practices, because the possibility exists that multiple branches of knowledge have or will become the object of integration when, alas, those individual branches are themselves questionable, and frequently are not internally integrated. The consequences include the possibility that interdisciplinary integration will be frustrated by defects in disciplinary knowledge, and that Foucault's complaints will be compounded indefinitely into the future.

It can occur that today's steadily enlarging interdisciplinary practices in higher education may yield something like a Pyrrhic Victory:

"a too costly victory: in reference to either of two victories of Pyrrhus, king of Epirus, over the Romans in 280 and 279 B. C., with very heavy losses".

---WEBSTER'S NEW WORLD DICTIONARY, Third College Edition (1993), New York: Prentice Hall, p. 1096.

If productivity in integrative studies is a concern, we may wish to review Kenneth Boulding's "three primary reasons for poor intellectual productivity":

- Unproductive Emulation
- Spurious Saliency
- Cultural Lag

---KENNETH BOULDING (1966), *The Impact of the Social Sciences*, New Brunswick: Rutgers University Press.

In this review, we may strive to avoid **emulating** the current behavioral stream and current practices. We may strive to test as carefully as we can the **saliency** of our current thinking by exhuming prior, relevant thinking; and trying to prioritize methods for use in doing integrative studies. In the process, we may try to avoid **cultural lag**-- i.e., we may try to engage in best practices as a consequence of reviewing the architecture of our knowledge.

In order to make advances in this respect, we have to acknowledge the hazard in working *only* at a high linguistic level. We can take some guidance from William James:

"Any question can be made immaterial by subsuming all its answers under a common head...The sovereign road to indifference, whether to evils or to goods, lies in the thought of the higher genus."

This view may, perhaps, call into question the frequent resort to metaphor in describing problematic situations. We return to this idea later in discussing the three-level "Alberts Pattern" for working systematically with ideas in organizational life.

We may take heart from the example of Lavoisier's integrative work in chemistry. In that work, we find a scholar, educated as a lawyer, taking on the task of upgrading the linguistics of a branch of science. As Antoine Lavoisier said:

"We cannot improve the language of any science without at the same time improving the science itself; neither can we, on the other hand, improve a science without improving the language or nomenclature which belongs to it."

Now it is time to look at those good assumptions that will be examined in more detail following their enunciation.

2. BASIC PROPOSITIONS FOR CHANGE IN ACADEMIA

- **Good Assumptions.** The following set of good assumptions is presented in a designed sequence, because these assumptions are interlinked. The context in which these assumptions are offered is academia, i.e., colleges and universities as a whole. Key aspects of these assumptions will be discussed later in the paper.
 - **G1. Foucault's Conclusions.** The conclusions reached by Michel Foucault³ (1926-1984) concerning the necessary reconstruction of knowledge are correct, for the reasons that he has given.
 - **G2. Lasswell's Infrastructure Conclusions.** The infrastructure conclusions reached by Harold Lasswell⁴ (1902-1978) concerning necessary conditions for developing effective public policy and for facilitating learning about broad-scope situations are correct, for the reasons that he has given.
 - **G3. Peirce's Insights.** The insights produced by Charles Sanders Peirce⁵ (1839-1914) about the role of logic, ethics, and esthetics in science and, more generally, in making our ideas clear, are correct, for the reasons he has given.
 - **G4. Harary's Mathematics.** The mathematics of "structural models", as set forth by Harary (1921-) et al⁶, which aggregates various mathematical unities into a larger unity, provides the mathematical basis for portraying the logic of disciplines through structural models.
 - **G5. Warfield's Interpretive Structural Modeling Process.** The process developed by Warfield⁷ (1925-) called "Interpretive Structural Modeling (ISM)" provides the computerized technological support (and insulation from not-understood mathematics) required to carry out the

³ Michel Foucault (1969): *L'Archéologie du Savoir*--translation (1993), *The Archaeology of Knowledge and the Discourse on Language*, translated by A. M. Sheridan Smith, New York: Barnes & Noble.

⁴ Harold D. Lasswell (1960), "The Techniques of Decision Seminars", *Midwest Journal of Political Science* 4, 213-236; (1963), *The Future of Political Science*, New York: Atherton Press; (1971), *A Pre-View of the Policy Sciences*, New York: American Elsevier.

⁵ Charles Sanders Peirce (1878), "How to Make Our Ideas Clear", *Popular Science Monthly* 12, January, 286-302. This article has been reproduced many times in many compendia, including several published in the last few years; e.g., James Hoopes (Ed.) (1991), *Peirce on Signs*, Chapel Hill: The University of North Carolina Press, 160-179.

⁶ F. Harary, R. F. Norman, and D. Cartwright (1965), *Structural Models: An Introduction to the Theory of Directed Graphs*, New York: Wiley.

⁷ J. N. Warfield (1974), *Structuring Complex Systems*, Columbus, OH: Battelle Memorial Institute, Monograph Number 4; (1976), *Societal Systems: Planning, Policy, and Complexity*, New York: Wiley (reprinted, 1989, Salinas, CA: Intersystems).

program of Foucault, applying the conceptualization set forth by Peirce, and converting Harary's analysis into a synthesis format.

- **G6. The Generic Design Science and Interactive Management.** The science of generic design and the management system called Interactive Management (IM) developed by Warfield⁸ and his colleagues, provide, respectively, the scientific foundation for collaborative system design, and the management practice to implement that scientific foundation. Incorporating ISM, IM provides the management processes required to carry out the program of Foucault, applying the conceptualization set forth by Peirce.
- **G7. The Infrastructure for Knowledge Development.** The special infrastructure required to carry out the IM processes consisting of (a) the Demosophia room and (b) the Corporate Observatory, both based in Lasswell's contributions, constitute the means to support the program of Foucault, applying the conceptualization set forth by Peirce, using the relevant Lasswell infrastructure conclusions (discussed later).
- **G8. The Spreadthink Discovery.** The discovery and articulation of "Spreadthink"⁹, revealing the universal variations in viewpoints associated with situations involving complexity, provides the rationale for dispensing with all non-scientifically-based group processes and dispensing with conventional group work environments, in favor of a process and infrastructure that is adequate to meet the demands of complexity.
- **G9. Indexes of Complexity.** The failure of academics and business managers to recognize the special requirements for success in working with complexity can be rectified, if the actors will gain an understanding of recently developed indexes of complexity¹⁰. The application of these indices will make clear when situations have to be dealt with in full recognition of the demands of complexity.
- **G10. The Boulding Explanation for Low Intellectual Productivity.** Kenneth Boulding's¹¹ explanation for low intellectual productivity can be applied to say why the ideas reflected in the foregoing nine points are slow to make inroads into academic institutions and other organizations. Put in a vernacular, (1) people frequently copy indiscriminately (with minor editing) what other people do without analyzing why that is a bad idea, (2) people are basically ill-equipped to prioritize ideas according to their importance, and so they work on less-important ideas, instead of assigning the proper importance to coming to grips with complexity, and (3) cultural change is inherently slow, because those with power attained that power by pursuing conventional approaches to difficult situations; and they don't see any reason to throw off those processes in favor of something they have not experienced (and can't or won't take the time to study or

⁸ John N. Warfield (1994), *A Science of Generic Design: Managing Complexity Through Systems Design*, 2nd Edition, Ames, IA: The Iowa State University Press; and John N. Warfield and A. Roxana Cárdenas (1994), *A Handbook of Interactive Management*, Ames, IA: The Iowa State University Press.

⁹ John N. Warfield (1995), "Spreadthink: Explaining Ineffective Groups", *Systems Research* 12(1), 5-14.

¹⁰ Staley, S. M. (1995), "Complexity Measurements of Systems Design", in *Integrated Design and Process Technology* (A. Ertas, C. V. Ramamoorthy, M. M. Tanik, I. I. Esat, F. Veniali, and Taleb-Bendiab, Editors), IDPT-Vol. 1, Austin, TX, 153-161. This paper describes four indexes, and their application in a large corporation. More recently a fifth index has been developed, which quantifies a logic property of a commonly-developed structure called a "problematique". This index is called the Aristotle index. It is the number of syllogisms contained in a problematique.

¹¹ Kenneth Boulding (1966), *The Impact of the Social Sciences*, New Brunswick, NJ: The Rutgers University Press. In this work Boulding identified three factors that are responsible for low intellectual productivity: (1) unproductive emulation, (2) spurious saliency, and (3) cultural lag.

experience).

3. THE PROBLEMATIC SITUATION AND THE LANGUAGE OF INQUIRY

A key issue in developing an integrative studies concept and practice involves the context within which integrative studies are carried out. The very term "interdisciplinary" immediately tends to narrow the context to include only those topics or themes that can be developed by an integration of academic disciplines. There is a powerful argument for adopting that context. The argument basically is that it is inside the institutional entity (i.e., the college or university), in which scholarly advancement of knowledge is most likely to occur. The institution, through integrative practice, is best-positioned because of the breadth of its component understandings, to focus upon integrative studies while, at the same time, producing educational benefits for students and faculty alike.

On the other hand, it is very clear that if integrative studies are limited to content found in academic disciplines, a large sector of opportunity for application is not overtly factored into the activities. Even more disappointing is an issue related to creating a language of integration to carry over directly to non-academic pursuits. The cost of replacing the word "interdisciplinary" with a more encompassing term seems modest, and the benefits seem potentially large. In so doing, the word "interdisciplinary" need not be dispensed with. On the contrary, it may become more linguistically acceptable (i.e., more authentic in usage) because it can be used as a restricted, but very focused, case of a more encompassing concept. It is notable that Foucault, in considering the requirements for broad knowledge reconstruction, chose the word "unity" to represent the higher genus of which "discipline" is a lower-level constituent.

- **The Initiation of Inquiry.** It is perfectly possible that any inquiry, be it disciplinary, interdisciplinary, or otherwise, can be doomed to failure simply because it begins with an underpinning of a bad assumption about the initiation of inquiry. Several philosophers have explored the issue of how to start an inquiry. Some of these have been discussed in an integrated context by the late F. S. C. Northrup¹². In comparing various incompatible views, one may conclude that the most appropriate view can be found by joining ideas from C. S. Peirce, John Dewey (at one time, briefly, a student of Peirce), and the Chinese tao of science.

Peirce dismissed Descartes' idea that the way to begin is to clear the mind, writing that one must recognize that the individual is endowed with a mass of cognition which could not be dispensed with, even if one wanted to. He used the colorful language *unshakeable cognitive burden* to describe this condition. Dewey put forth the concept of *problematic situation* as a context for beginning an inquiry. Going back much further, the Chinese concept of the tao proposes to begin

¹² F. S. C. Northrup (1979, originally 1947--Macmillan), *The Logic of the Sciences and the Humanities*, Westport: Greenwood Press.

with thought of the entire universe as available to the thinker; and then to remove gradually from that universe, in a series of modest steps, only those aspects of that universe not judged to be significant in defining the scope of the investigative arena, or the problematic situation itself.

A problematic situation will normally be embedded in a larger context. In posing a context, with an enhanced linguistic component, the following ideas are set forth.

■ **Three Contexts.** The following three contexts can be chosen for purposes of inquiry and, possibly of application:

- The Academic Context (Higher Education, Scenario A)
- The Global Context (Scenario B)
- Interactions Between the Academic Context and the Global Context (Scenario C)

Each of these contexts will be described separately in a brief scenario, simplified to highlight areas of special importance.

■ **Scenario A (The Academic Context, Higher Education).**

In Scenario A, there is an organization called the university (or the college). In this scenario, programmed knowledge is delivered by disciplinary practice and interdisciplinary practice.

■ **Scenario B (The Global Context).**

In Scenario B, most individuals are operating in several organizations (small, medium, large; family, work, state, nation, etc.), where they face many situations requiring some kind of action. Some of these situations can be dealt with by long-established practices, known to be effective in those situations. At another extreme, some of these situations are problematic, involving recourse to a wide variety of types of knowledge, some of which is not at hand and, if it were to be applied, would have to be brought to a suitable status, developed through some kind of integrative process.

■ **Scenario C (Interaction Context).**

In Scenario C, the individual strives to apply knowledge and experience in Scenario B to a problematic situation, including in the effort the choice and application of relevant resources gained while operating in Scenario A.

How can the concept "unity" be made operational across these contexts?

■ **Operationalizing the Concept of a Unity (along lines of Foucault's thinking).** The *unities* may be allied with and co-labeled with the *Scenarios*.

The **type A** unities are mostly those of the disciplines, with some having been developed in

interdisciplinary practice. In some instances, e.g., a unity (e.g., history), often described as a social science discipline, can have interdisciplinary attributes.

The **type B** unities constitute a much larger class. They include beliefs incorporated in some organizational culture, e.g., religions, industrial practices, and information systems. Since Scenario B encompasses Scenario A, the type A unities are also included in the type B unities.

In significant contrast with the type A and B unities, which are mostly *content-based*, the **type C** unities are largely *process-based*. That is, while they have content, it is about process. They are bodies of knowledge and experience that relate to how to integrate knowledge and experience from the type A- and type B-unities.

While unities can be described as Type A (disciplinary), Type B (global), and Type C (interactive), unities can also be classified as floating, submerged, or anchored, by examining their underpinnings in formal logic:

- **Floating Unity.** A floating unity is supported *merely* by a natural language, and does not contain any formalisms from formal logic. Hence its origins in logic are obscure. Social science unities represent this type.
- **Submerged Unity.** A submerged unity is neither floating nor anchored. Its representation is a mix of natural language and derivative formalisms. Physical science and technological unities are almost all of this type.
- **Anchored Unity.** An anchored unity is reducible to a set of formalisms from formal logic, although natural language can be used to clarify its nature.

These distinctions are very relevant to knowledge integration, as will be discussed further.

- **Focus of This Paper.** This paper is primarily involved with understanding what types of processes (C-Unities) are appropriate for those problematic situations in a B-Scenario which require specific attention to complexity. What is required of those processes in order to make the integration of A- and B-unities effective? Secondly, this paper is involved with explicating how floating or submerged unities can be converted to anchored unities.

For purposes of expanding on this focus, it is necessary to have an appropriate definition of the term "system", since the act of integration involves the construction of a new system. Vickers has warned against interpreting the term too narrowly:

"The concept of systemic relations, though not new, has been developed in the last few decades to an extent which should be welcome, since it is the key to understanding the situations in which we intervene when we exercise what initiative we have and especially to the dialectic nature of human history. It has, however, become so closely associated with man-made systems, technological design and computer science that the word 'system' is in danger of becoming unusable in the context of human history and human culture."

---SIR GEOFFREY VICKERS (1980), *Responsibility--Its Sources and Limits*, Seaside: Intersystems.

For that reason, we choose as the needed, broad definition, that of a fine and very productive American scientist. A system (following J. Willard Gibbs) is:

"any portion of the material universe which we choose to separate in thought from the rest of the universe for the purpose of considering and discussing the various changes which may occur within it under various conditions".
[This definition is not widely known among systems scholars.]

---MURIEL RUKEYSER (1942, 1988), *Willard Gibbs*, Woodbridge, CT: OxBow (reprint of the 1942 Doubleday, Doran Edition).

At this point, it is possible to summarize briefly a platform from which continuing movement in inquiry seems to be justified, as shown in Table 1.

Table 1. Building a Platform for Initiating Inquiry	
Operating Concept	Higher-Level Umbrella Term
Problem	Problematic Situation
Discipline	Unity
Academic	Global
Interdisciplinary	Unity
Topical Area	System
Prose	Combined Prose and Graphics

4. THE MOST ESSENTIAL PRODUCT OF SUCCESSFUL INTEGRATIVE STUDIES SHOULD BE A STRUCTURED (QUALITATIVE) SYSTEM MODEL

- **Human Knowledge.** All human knowledge is constructed by human beings as collections of models, formal, informal, or hybrid (a mixture of formal and informal) from origins in individual belief. Consequently, in elevating belief to the status of knowledge, integration is essential. If the integration acknowledges, in its practice, that models are being built through integration, the possibility of drawing on some advantages of formalisms for integration comes into view. If the concept of system is invoked, portions of a domain of knowledge known variously as "systems analysis" or "systems science" might be tapped for ideas.

Formal models are numerant, structural, or hybrid (a mixture of numerant and structural). Structural models are linear or non-linear. A linear structural model is isomorphic to a directed graph, so that a directed line can be drawn passing through all vertexes and lines without

touching any more than once.

- **Model Spaces.** Model Spaces are formal and mathematical (heavily symbolic and programmable) of three major types: root, intermediate, and application-oriented. A *root space* is a mathematical space that forms a comprehensive framework for developing and positioning a formal model, as distinguished from any of its submodels. An *intermediate space* is like a root space, but serves only for proper submodels, and may not be generalizable to the parent models. An *application-oriented space* typically is idiosyncratic to a particular, narrow-context application and, quite frequently, is very poorly suited to extension into lateral or more inclusive domains.

But, as Hayek said, that does not prevent such extensions from being carried out:

"During the first half of the nineteenth century a new attitude made its appearance. The term science came more and more to be confined to the physical and biological disciplines which at the same time began to claim for themselves a special rigorousness and certainty which distinguished them from all others. Their success was such that they soon came to exercise an extraordinary fascination on those working in other fields, who rapidly began to imitate their teaching and vocabulary. Thus the tyranny commenced which the methods and technique of the sciences in the narrow sense of the term have ever since exercised over the other subjects."

---F. A. Hayek, *The Counter-Revolution of Science: Studies on the Abuse of Reason* (1955), New York: The Free Press.

- **The Situation.** Amelioration of undesired consequences of complexity involves the study of situations and systems. A *situation* (the shorter view of "problematic situation") is a triad consisting of (a) a human component (an individual or an aggregation of individuals), (b) other systems contained in the situation, and (c) their respective environments. A *universe* is a set of all situations relevant to a chosen investigation.

5. MODELS OF COMPLEXITY FURNISH LEARNING OPPORTUNITIES

In his justly-famous paper published in 1878, titled "How to Make our Ideas Clear", Charles Sanders Peirce talked about false distinctions that are sometimes made in assessing beliefs. Of relevance to situations involving complexity, he wrote the following:

"One singular deception ... which often occurs, is to mistake the sensation produced by our own unclearness of thought for a character of the object we are thinking. Instead of perceiving that the obscurity is purely subjective, we fancy that we contemplate a quality of the object which is essentially mysterious..."

"...So long as this deception lasts, it obviously puts an impassable barrier in the way of perspicuous thinking; so that it equally interests the opponents of rational thought to perpetuate it, and its adherents to guard against it."

This idea can be paraphrased somewhat, and turned into a definition of "complexity". First of all, it is surely true that the vast majority of modern thought about complexity perceives it to be a property of what is being observed, instead of being a subjective response to the not-

understood. The language itself clearly demonstrates this, in the common use of terms such as "complex system", and "complex problem". Yet it is easy to imagine this: if the human being had the mental power to comprehend everything that was of any interest, there would be no such thing as a complex system or complex problem in the usual sense, or of complexity in the sense discussed here. Clearly then, **the very existence of complexity is directly connected to human mental limitations. Complexity is not a property of what is being observed, but rather is "a sensation" arising out of our own "unclearness of thought",** when we are engaged with what we are observing¹³.

While this definition may be thought surprising, one of its notable attributes is that it allows for the possibility that complexity may be reduced or even eliminated, by a process called "learning".

D. W. Harding described the views of the late contemporary French philosopher and chairman of the history of systems of thought at the Collège de France, Michel Foucault (1926-1984), reflected in his masterpiece on the "archaeology of knowledge", as follows:

"our own current intellectual life and systems of thought are built on assumptions profoundly taken for granted and not normally exposed to conscious inspection, and yet likely in time...to be discarded."

As Foucault stated::

"The manifest discourse, therefore, is really no more than the repressive presence of what it does not say; and this 'not-said' is a hollow that undermines from within all that is said."

When or if models of complexity fail to inspire confidence, perhaps it is often because of **what is not said** in the models. And perhaps the reasons for the not-said include both lack of comprehension, and undue addiction to inadequate modes of representation of complexity. A prolonged period of research on complexity has surfaced **only seven** means of representation that are scale-independent, and provide the opportunity to portray visually the total, integrated, current comprehension of a situation. None of these is observable in publications by most scholars of integrative studies.

6. INTEGRATIVE STUDIES MUST TAKE COMPLEXITY INTO ACCOUNT OVERTLY

Because of the sparseness of the array of modes of representation of complexity, integrative studies should become amenable to choosing from those seven modes those that are particularly

¹³ Three publications present relevant material. They are: (1) G. A. Miller (1956), "The Magical Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information", *Psychology Review* 63(2), 81-97; (2) H. A. Simon (1974), "How Big is a Chunk?", *Science* 183, February 8, 482-488; and (3) J. N. Warfield (1988), "The Magical Number Three, Plus or Minus Zero, *Cybernetics and Systems* 19, 339-358.

relevant to a situation. The seven modes are:

- **Arrow-Bullet Diagrams** *(which are mappable from square binary matrices, and which correspond to digraphs)*
- **Element-Relation Diagrams** *(which are mappable from incidence matrices, and which correspond to bipartite relations)*
- **Fields** *(which are mappable from multiple, square binary matrices, which correspond to multiple digraphs, and which may be extended into Tapestries)*
- **Profiles** *(which correspond to multiple binary vectors, and also correspond to Boolean spaces)*
- **Total Inclusion Structures** *(which correspond to distributive lattices and to power sets of a given basis set)*
- **Partition Structures** *(which correspond to the non-distributive lattices of all partitions of a basis set)*
- **DELTA Charts** *(which are restricted to use with temporal relationships, and which sacrifice direct mathematical connections to versatility in applications)*

These various structural types (which are discussed extensively in the references) reflect two necessities:

- **Overt Modal Choice.** The necessity to choose modes of representation that are adequate to portray complexity in learning situations
- **Resort to Formalism.** The necessity to define these modes in terms of established branches of mathematics, in order to clarify what they are, and in order to take advantage of the principles of mathematical operations upon large information sets, including large numbers of relationships

While there is no escaping these two necessities, two unfortunate consequences ensue when they are accepted:

- **Learning Time Must be Allocated.** It is necessary to spend a significant amount of time in developing the representations; more than academics will normally dedicate, especially in group settings, given the current institutional, architectural infrastructure
- **The Superficial Must be Consciously Foregone.** People who lack the mathematical understanding of the foundations beneath these modes of representation have a tendency

to take the easy way out and resort to unsupported superficialities (e.g., to William James' "higher genus")

The first of these consequences can be ameliorated by efficient group learning processes, supported by adequate spatial infrastructures. The second can be ameliorated by transferring the mathematical burden to the computer; an act which also greatly enhances the efficacy of the group processes. Both of these requirements for amelioration are now adequately understood, tested, and documented for purposes of application in long-standing or envisaged situations.

The central conclusion is that, in order to cope adequately with complexity, it is necessary in its overt recognition, to apply well-designed and tested processes of the form documented under the rubric "Interactive Management"¹⁴. Fortunately these processes, like the formalisms themselves, can be effective in working with any of the unities.

7. THE SCIENCES FURNISH A TEST BED FOR INTEGRATIVE STUDIES

Integrative studies are broadly inclusive in scope, encompassing the sciences, the humanities, and the professions. Each of these areas has its own distinctive cultural features and educational concerns. Rather than attempt to articulate integrative studies across the board, this paper will limit more detailed attention to the sciences, with the belief that what is discussed in that context will be transferable in some ways, at least, to the other areas. Even to accomplish this, it is necessary to rethink science from the perspective of requirements for integration.

- **Science.** A science is a body of evolving knowledge consisting of three variously-integrated components: foundations, theory, and methodology. (This definition is not generally known inside or outside the systems arena, whether academic or practicing.) Foundations inform the theory and the theory informs the methodology. The volume of knowledge is smallest in the foundations and largest in the methodology. The domain of a science consists of the science and its applications. All science is evolutionary. Evolution typically occurs by comparing the congruence between the science and results observed in its applications. Sciences can be generally described as falling into one of two major categories: descriptive science and normative science. To appreciate the distinctions, it is necessary to expand older conceptualizations of what science is. To do otherwise is to limit science to a purely descriptive role; instead of accommodating to the larger role of applying its descriptions to help resolve complexity in today's world.
- **The Work Program of Complexity.** The "Work Program of Complexity" makes up one side of a matrix. The other side is the "Behavioral Menu". Each of the sixteen cells in the Behavior-Outcomes Matrix shown in Figure 1 is a unique area of study that can be

¹⁴ J. N. Warfield and A. Roxana Cárdenas (1994), *A Handbook of Interactive Management*, Ames, IA: The Iowa State University Press; J. N. Warfield (1994), *A Science of Generic Design*, 2nd Edition, Ames, IA: The Iowa State University Press.

supported by scientific knowledge. Those cells which contain items show the names of one or more of the 20 Laws of Complexity¹⁵ applicable to that cell. The Work Program (across the top) reflects four activities: Description, Diagnosis, Design, and Implementation. Of these four, Description reflects the conventional view of science, i.e., descriptive science. Diagnosis may have both a descriptive and a normative science underpinning. Design, based on the Description and Diagnosis; and Implementation, as well; both reflect possibilities for applying normative science.

- **Descriptive Science.** Descriptive science involves the creation of a language directly applicable to relatively precise delineation of a situation, along with the conduct and analysis of a sufficient number of observations to make possible an adequate description of the situation. As mentioned previously, for situations involving complexity, only seven descriptonal modes have been determined so far to be adequate for representations.
- **Normative Science.** Of the many relevant discussions of science, one may note those related to the "normative sciences". The view of Charles Sanders Peirce, an outstanding scientist and logician, is described by Potter as follows:

"...logical inquiry is (for Peirce, at least) one of three normative sciences whose character is ultimately comprehensible only in reference to the two other normative sciences (esthetics, conceived as the investigation of ultimate ends, and ethics, conceived as the investigation of self-controlled conduct)."

---From: the late Father VINCENT POTTER (of Fordham University) in his 1996 book titled *Peirce's Philosophical Perspectives* (New York: Fordham University Press).

The processes of Interactive Management accommodate both descriptive and normative science. They do so by providing computerized assistance in coping with the logical inquiry, while providing ample opportunity for those engaged in the inquiry to apply their sense of ethics and esthetics in the decisions made in Diagnosis, Design, and Implementation.

For this to be possible, the processes must reflect a thorough study of human behavior in carrying out such activity, and must provide corrective means to overcome both (a) the well-known limitations on individuals in working with information, and (b) the less well-known, but adequately described, group pathologies that limit groups in working with information.

8. FORMALISMS PROVIDE A STRONG BASIS FOR ANCHORING INTEGRATIVE STUDIES

Formal languages and the formalisms that they represent provide a strong basis for anchoring integrative studies. To realize this, one needs a new image of the constituents of the argument.

¹⁵ Articulation of these Laws has evolved slowly over a period of more than 20 years. A full description is available only from the author.

		OUTCOMES			
		DESCRIPTION	DIAGNOSIS	PRESCRIPTION (DESIGN)	IMPLEMENTATION
PROCESS		<ul style="list-style-type: none"> ■ Limits ■ Triadic Necessity & Sufficiency ■ Universal Priors 	<ul style="list-style-type: none"> ■ Success & Failure ■ Universal Priors 		<ul style="list-style-type: none"> ■ Gradation ■ Validation
INDIVIDUAL		<ul style="list-style-type: none"> ■ Limits ■ Triadic Compatibility ■ Small Displays 		<ul style="list-style-type: none"> ■ Requisite Parsimony ■ Requisite Saliency 	
GROUP		<ul style="list-style-type: none"> ■ Limits ■ Uncorrelated Extremes 	<ul style="list-style-type: none"> ■ Inherent Conflict ■ Structural Underconceptualization ■ Diverse Beliefs 	<ul style="list-style-type: none"> ■ Requisite Variety ■ Induced Groupthink 	
ORGANIZATIONAL		<ul style="list-style-type: none"> ■ Limits ■ Organizational Linguistics ■ Vertical Incoherence 	<ul style="list-style-type: none"> ■ Forced Substitution ■ Precluded Resolution ■ Vertical Incoherence 		
B E H A V I O R					

Figure 1. BEHAVIOR--OUTCOMES MATRIX (Understanding The Work Program of Complexity)
 showing which Laws of Complexity relate strongly to which combination of behavior and outcome.

- **Formal Language.** *"formal language. An uninterpreted system of signs. The signs are typically of three sorts: (1) variables, for example, sentence letters p, q, r, s; (2) connectives, for example, \vee , $\&$, \neg , by which signs are joined together; and (3) punctuation devices, such as brackets, to remove ambiguity. There are also formation rules telling how to string signs together to form well-formed formulae, and transformation rules telling how to transform one string of signs into another.*

"Formal languages in this sense are just sets of marks permutable by rules, much as chess notation is. They may, however, be interpreted. Thus if (1) the variable letters are made to stand for propositions, (2) \vee , $\&$, \neg to stand for 'or', 'and', and 'if-then' and (3) the transformation rules are made deduction rules, then the formal language has been interpreted as a system of logic.

"Distinction must be made between formal languages (uninterpreted systems of marks) and artificial languages (interpreted formal languages which are, however, not natural languages as vernacular English is)."

---ANTHONY FLEW (1984), *A Dictionary of Philosophy*, Revised Second Edition, New York: St. Martin's Press, pages 123-124.

- **Subsumption.** A critical aspect of the organization of knowledge is the act of subsuming. Subsuming connects two concepts through their relative positions in the development of an artificial language.

If we represent "is subsumed within" by "*sub*", A *sub* B means that A is subsumed within B, which means as well that A is included in B.

Not generally viewed as an operation, requiring attention nonetheless, is an operation sometimes applied in academia, called "supersumption"--more or less the opposite of subsumption.

- **Supersumption.** If we represent "supersumed above" by "*sup*", the two statements A *sup* B and A *sub* B mean that (a) although A *sub* B (as just defined above), (b) nonetheless, A is used (erroneously, as a rule) as a surrogate for B, i.e., that A supersumes B, usually to protect and extend academic turf.
- **Formalism.** *"formalism 1. (mathematics) A view pioneered by D. Hilbert (1862-1943) and his followers, in which it was claimed that the only foundation necessary for mathematics is its formalization and the proof that the system produced is consistent. Numbers (and formulae and proofs) were regarded merely as sequences of strokes, not as objects denoted by such strokes. Hilbert's programme was to put mathematics on a sound footing by reducing it (via arithmetic) to consistent axioms and derivation rules, the former being certain series of strokes, the latter ways of manipulating them. Later Gödel¹⁶ showed that the consistency of arithmetic cannot be proved within the system itself, thus demonstrating the*

¹⁶ Gödel's work achieved an unwarranted level of capitulation that has, to a considerable extent, brought progress in the evolution of logic as a tool of learning to a screeching halt. For a discussion of this in more detail, see: J. N. Warfield, *Some Magnificent Academic Trusels and Their Social Consequences* (1992), Fairfax, VA: IASIS. In that document, a "trusel" is defined as: "an idea or finding that is widely perceived to be true, but which is largely useless (or even of negative value)". A "magnificent academic trusel" (e.g., Gödel's Theorem) is defined as "one that has been widely acknowledged for its intellectual content (explicitly or implicitly), but without a corresponding amount of attention being given to its utility or even to its potential negative value for society".

impossibility of achieving part of the Hilbert programme. 2. (in ethics and aesthetics) Emphasis on formal issues at the expense of content. The term is generally employed by opponents of such attitudes."

---ANTHONY FLEW (1984), *A Dictionary of Philosophy*, Revised Second Edition, New York: St. Martin's Press, page 123.

Sometimes the following type of formalism is involved:

- **Derivative Formalism.** A formalism that incorporates an anchored unity only by contextual implication, without formal expression of the anchored unity.
- **Steps in Applying a Formalism.** Formalisms are available to unities at their beck and call. But the use of a formalism as a way of representing some aspect of a unity can be described normatively as follows:
 - **Step 1. Selecting a Unity.** Select a unity for which a choice of formalisms might be appropriate to represent complexity.
 - **Step 2. Identifying a Relevant Formalism.** Identify a particular formalism whose construction is compatible with the descriptive requirements of the chosen unity.
 - **Step 3. Making Concept Associations.** Make associations of specific concepts from the unity with specific symbols in the formalism [a step in converting the formalism from its inherent non-interpretive state (see the excerpt from Flew given above) to an interpretive state.]
 - **Step 4. Making Relationship Associations.** Make associations among those chosen concepts with particular relationship types, in order to enable relationships to be interpreted.
 - **Step 5. Selecting a Consistency Test.** If consistency is admired, use any available consistency test from the chosen formalism or, if the chosen formalism has none, select a formalism that does have one, and which is compatible with the formalism chosen earlier.
 - **Step 6. Constructing a Language.** Solidify the presentation into an "artificial" or "object" language.
 - **Step 7. Assigning Numerical Values.** If it is desired that concepts in the new language should be numerically quantified, assign numerical values to the appropriate concepts. (It may be necessary to carry out experiments in order to determine numerical assignments.)
- **Association.** Having just used the word "association", it is best now to specify exactly what it means. A concept of interest in the chosen unity is paired uniquely with a particular symbol from the formalism. If, for example, the formalism includes the symbol x , and if the unity involves electrical current, one may make an association between the symbol x and the electrical current. One may (and usually does) make a prior association involving a new symbol, such as I , so that there is really a double association:

$$x \leftrightarrow I, \quad I \leftrightarrow \text{electrical current}$$

When this is done, it is usually done *en masse* so that, whatever symbolism may have been chosen to present the formalism, that symbolism may be replaced in totality with a new symbolism. The link between the interpretive term, such as electrical current, with the original formalism may then be lost in deference to the revised symbolism particular to a specific unity.

This loss of link tends to invoke the culture of the unity and serves, as well, to distance that culture from the original formalism. While this is very convenient in applications of the unity, it tends to mask the debt which the unity owes to the originators of the formalism and may, over time, obscure the connection with the formalism. If that occurs, some consorts of the unity may even depart from the formalism without notification, thereby losing the structural and substantive integrity which (one hopes) was present in the chosen formalism.

Associations may be most powerful when they involve the Theory of Relations as the formalism. This is because the Theory of Relations, as implemented in the computer-assisted process called "Interpretive Structural Modeling", can be applied to give major help to people who are interested in a careful organization or reorganization of existing unities. Associations are prominent and overt, and apply both to the elements and to the relationships.

■ **Assignment.** Assignment can be carried out following association.

The formalism can be seen as the broadest type of non-interpretable unity. It is essential that this type *not* be interpretable (in Flew's sense), in order that associations can be made to convert this type of unity into interpretable form. **This is precisely the key to interdisciplinary integration.** As soon as a set of associations is complete, we have an *artificial unity*, which is narrower in scope of application than the formalism. Still, the artificial unity has some generality, because it is not restricted to particular numerical values.

Assignment refers to the attachment of a numerical value to an association or, more generally, the assignment of a set of values to the set of associations. We must keep in mind, when making assignments, that the set of associations is tantamount to a set of constraints on allowable assignments. So, if we have a formula like $I = E/R$ among the set of associations, we can only assign to two of the three components in that formula; whereupon the third one is determined.

The passage from formalism to association to assignment is a passage from the very general to the very specific. This is the kind of passage that underpins applications of science to the so-called "real world". When the passage is denied or ignored, by lopping off any reference to the formalism (as the chaos theorists and adaptive systems theorists, among others, are likely to do), we have a kind of "sin against science" which characterizes, for example, much of the U. S. scientific and technological society. Being a very inventive society, with strong attachment to independent behavior, there is a large reluctance even to retrace thought to the formalisms, much less to be disciplined by them, except in instances where there is a long history of adherence; in which the rare, but occasional, allegiance to a formalism is a habit of long standing.

■ **When are association and assignment justified?** The justification of association and assignment to a formalism comes about in at least two possible ways:

- As the instantiation of a hypothesis that is going to be tested
- As the solidification of an adequate body of empirical evidence

■ What is meant by "integration of sciences"?

This is a phrase that may be tossed about lightly, without strict meaning. It can be given a rather strict meaning, if it is seen in the light of the Domain of Science Model.

■ What is the "Domain of Science Model (DOSM)"?

The Domain of Science Model (DOSM) is a reentrant graphics model. It portrays a science as a body of knowledge arrayed in three parts:

- Foundations
- Theory
- Methodology

In this reentrant model, all of whose components are subject to revision in the light of new discoveries in the relevant domain,

Foundations → Theory → Methodology → Applications → Foundations.

where the arrow represents this relationship: "inform(s)".

Through the relationship among the components, every part of the model is related to every other part of the model.

In terms of size of presentation, the Foundations form the smallest part, the Theory forms a larger part, and the Methodology forms a still larger part.

Integration of sciences is best accomplished by integrating at the level of the Foundations, and then proceeding to integrate the Theory according to the discipline imposed by the integration of the Foundations. After the Foundations and Theory are integrated, one can proceed to integrate the Methodologies. This process is indefinitely iterative, and dealt with flexibly.

For most established sciences, the part of the Domain of Science Model that involves Applications can be very small. To be included in the DOSM of a science, it must be true that **only that science is required for applications**. But most applications of science can benefit from or even require an integration of sciences. For this reason, those sciences that represent the integration of several sciences often have much larger Applications components than the individual component sciences.

Unfortunately, there is only one science that today is overtly organized according to the DOSM (i.e., makes clear which is which among the three components). That is the "science of generic

design"¹⁷. It is so organized, because the DOSM was used to discipline the creation of that science. Perhaps, some day, denizens of more established sciences will understand the need and benefit of reorganizing those sciences to reflect the personal discipline imposed by following the DOSM. In this respect, Michel Foucault can be seen as the creator of the imperatives and some of the language for carrying out such an adventure. In his *"The Archaeology of Knowledge"*, as reflected in A. M. Sheridan Smith's translation, Foucault describes this view of reconstitution:

"the reconstitution, on the basis of what the documents say, and sometimes merely hint at, of the past from which they emanate and which has now disappeared far behind them...[and on the basis of] transformations that serve as new foundations, the rebuilding of foundations."

And later, in striving to define more precisely what is meant by "the archaeology of knowledge":

"It is an attempt to define a particular site by the exteriority of its vicinity; rather than trying to reduce others to silence, by claiming that what they say is worthless."

The definition of "a particular site" in science, can be carried out through the reconstitution of the science, as disciplined by the DOSM. And when that is done the exteriority of its vicinity can be enlarged if adjacent or proximity sciences, or overlapping sciences, can themselves be so reconstituted. Until that occurs, relatively slow evolution of applications of integrative sciences can be confidently predicted.

Some examples of this activity appear in Tables 2, 3, and 4. For each instance, and generally, all of the formalisms that are part of the chosen formal language (mathematical system) can be applied in working with aggregates.

**TABLE 2. FORMALISMS AS THE BASIS
FOR APPLYING SCIENCE
First Example: Physics, Electricity**

1. Choose the appropriate formalism from the many available in mathematics
2. The Chosen Formalism: $x = y/z$
3. Make Associations: $I = E/R$
4. Make Assignments: $E = 100, R = 10$
5. Compute Inference: $I = 10$

¹⁷ John N. Warfield (1994): *A Science of Generic Design: Managing Complexity Through Systems Design*, Second Edition, Ames, IA: The Iowa State University Press (first published in 1990 in two volumes in Salinas, CA: Intersystems).

**TABLE 3. FORMALISMS AS THE BASIS
FOR APPLYING SCIENCE**

**Second Example:
Situational Definition**

1. Choose the appropriate formalism from the many available in mathematics
2. The Chosen Formalism: Set theory; set operations: membership, inclusion, union, disjunction, Cartesian products of all orders; lattice isomorphisms.
- 3 and 4 combined. Make Associations and Assignments: Identify key situational set types and relationship types. Give them symbolic names and application names.
5. Compute Inference: Not required in definitional algorithms

**TABLE 4. FORMALISMS AS THE BASIS
FOR APPLYING SCIENCE**

Third Example: Computation of Structure

1. Choose the appropriate formalism from the many available in mathematics
2. The Chosen Formalism: $a_i R b_j = s_{ij}$;
 $M^2 = M$; M a binary matrix;
matrix operation is Boolean.
3. Make Associations: Problem i ; Problem j ; significantly aggravate; Connection Digraph.
4. Make Assignments: Does problem i aggravate problem j ?
 $s_{ij} = 0$, "no"; $= 1$, "yes"
5. Compute Inference:
 $s_{ij} = 1$ and $s_{jk} = 1$, implies $s_{ik} = 1$; as basis for matrix operations.

9. THE ORGANIZATION IS THE ACTION VENUE

Because of the heavy demands for cooperative group activity in working with complexity, it is natural that the organization should be the venue for the work.

- **Complexity Reduction Through Structural Thinking.** To illustrate how the fourth

component (organizations) of the Behavioral Menu in Figure 1 is dealt with, two examples of the application of the Structure-Based School approach to resolving complexity will be presented. The first example is illustrated by experience with redesign of the U. S. Defense Acquisition System, using design and process contributions from the Structure-Based School¹⁸.

Table 5 describes three levels in a vertically-integrated (inclusion) structure relevant to the problematic situation. The three levels are here described as the "Operational Level, the Tactical Level, and the Strategic Level". These names are chosen to reflect somewhat standard usage in the management of large organizations. This 3-level pattern is called "The Alberts Pattern" after its discoverer, Professor Henry Alberts¹⁹. A similar pattern, differing only in the numerical data, was independently found in a systems engineering curriculum study in Mexico²⁰. Notably, the "higher genus" is included here, but only as the overarching component; while extensive detail at lower levels in the hierarchy of information amplifies and elucidates the higher levels.

In the Operational Level, as indicated in Table 5, 678 problems relative to system acquisition were collectively identified (by more than 300 program managers who were active in defense acquisition management). In the Tactical Level, these 678 problems were placed in 20 *tactical categories*. Finally, in the Strategic Level, these 20 categories were placed in 6 *strategic domains*.

In his dissertation, Professor Alberts indicated that one of the two main objectives of his work was to use that work **to represent a prototype process for organizational redesign**, an extensive application of a designed process for reducing complexity. Complexity was reduced dramatically as the work progressed through the three levels. When completed, a highly transparent representation of the acquisition system was **available**. This allowed persons in the operational aspects of acquisition to relate the problems they work with every day to the higher-level categories; and vice versa. As a result, a redesign of the system could be carried out that reflected high visual capability in connecting design options to problems at all three levels. It is very likely that because of this extensive referential transparency, the relevant legislation passed by the U. S. Congress involved only minimal modification to the results coming from this work. The legislation, identified as Public Law 103-355, October 13, 1994, is cited as the "*Federal Acquisition Streamlining Act of 1994*".

¹⁸ J. N. Warfield and S. M. Staley (1996), "Structural Thinking: Organizing Complexity Through Disciplined Activity", *Systems Research* 13(1), 47-67.

¹⁹ Henry C. Alberts (1995), "Redesigning the United States Defense Acquisition System", Ph. D. Dissertation, Dept. of Systems Science, City University, London, United Kingdom.

²⁰ A. R. Cárdenas, J. C. and Rivas (1995), "Teaching Design and Designing Teaching", in *Integrated Design and Process Technology*, (A. Ertas, C. V. Ramamoorthy, M. M. Tanik, I. I. Esat, F. Veniali, and Taleb-Bendiab, Editors), IDPT-Vol. 1, 111-116.

Table 5. Two Examples of the Alberts Pattern in Organizations

Organization	Number of Elements (Operational Level)	Number of Element Categories (Tactical Level)	Number of Element Domains (Strategic Level)
U. S. Defense Acquisition System	678 problems	20 problem categories	6 problem domains
Instituto Tecnológico y de Estudios Superiores de Monterrey--Industrial and Systems Engineering	270 design options	20 design option categories	4 design option domains

A similar reduction in complexity occurred in the Mexican work. By developing the capacity to work back and forth among the three levels of the inclusion structure, from the very specific, to the general oversight areas, a coherent insight and correspondingly coherent approach to effective management of what had been relatively unmanageable becomes very feasible²¹.

- **The Lasswell Triad.** The possibility of broad-based learning about very large systems becomes more realistic when what is called here "The Lasswell Triad" is understood. Harold Lasswell (1902-1978) was a political scientist, one of the foremost authorities in that field. As a faculty member, he taught law and political science at the University of Chicago, Yale, and elsewhere. Author of many books and papers, he originated key ideas relevant to the effective design and understanding of public policy, which remain essentially dormant today.

One of his key views was expressed as follows:

"Our traditional patterns of problem-solving are flagrantly defective in presenting the future in ways that contribute insight and understanding"

The Lasswell Triad is responsive to this view, in part. It consists of these three concepts:

- The decision seminar (taking place in a specially-designed facility)
- The social planetarium
- The prelegislature, or pre-congress

²¹ J. N. Warfield and S. M. Staley (1996), "Structural Thinking: Organizing Complexity Through Disciplined Activity", *Systems Research* 13(1), 47-67.

In brief, here are the key ideas involved in this Triad:

- **The Situation Room.** First, a special facility needs to be put in place, where people can work together on design of complex policy (or other) issues, and where the display facilities have been carefully designed into the facility, so that they provide prominent ways for the participants to work with the future "in ways that contribute insight and understanding".
- **The Prelegislature.** Second, this special facility should be used extensively to develop high-quality designs long before legislatures or corporate bodies ever meet to try to resolve some complex issue facing them by designing a new system (e.g., this is a sensible way to go about designing a health-care system to which the political establishment can repair for insights and such modifications as seem essential).
- **The Observatory.** Once the design has been accepted, the observatorium is designed and established so that people can walk through a sequential learning experience, in which they gain both an overview and an in-depth understanding of the system that has been designed and which, most likely, will be prominent in their own lives.

The observatorium is a piece of real estate, whose building interior can be loosely compared with that of the Louvre, in that it contains a variety of rooms, and facilitates rapid familiarization with their contents by the persons who walk through that property. Further analogy comes from the recognition of the importance of wall displays (with electronic adjuncts), large enough in size to preclude any necessity to truncate communications; and tailored to help eradicate or minimize complexity in understanding, both broadly and in depth, the nature of the large organization; its problems, its vision, and its ongoing efforts to resolve its difficulties. Comparison with the planetarium for envisaging a broad swatch of the sky is self-evident.

The descriptions just given represent only modest deviations from the Lasswell Triad, but slight changes in nomenclature have been adopted for purposes of this paper.

Given that relatively little has been done with the Lasswell Triad, two questions might arise. The first might be: "Why?". Another might be: "Are there additions that have to be made that, when integrated with the Lasswell Triad, provide a practical means for enhancing greatly the design, management, amendment, and understanding of large, complex systems? This last question will now be answered: "Yes".

No one would expect that the observatorium would be brought into place unless the "art" required to fill it were available, and if the topic were of vital social importance.

It would, therefore, be important to have conceived and created the situation room required for effective group work, and to have conducted the necessary prelegislative activity to provide the raw display information for the observatorium.

A situation room of the type desired was developed in 1980, and has since been put into place in a variety of locations²². Rooms of this type provided the environment for the Alberts work, and for many other applications of Interactive Management²³. Thus the first essential preparation for the observatorium is complete.

The Alberts application, and other ongoing applications have and are providing the second essential raw display information.

What kinds of displays are required for the observatorium? These displays must meet stringent communication requirements. In brief, they must meet the demands of complexity for effective representation. This means, among other things, that they must be large, and they must cater to human cognitive requirements. At present, the displays will be chosen from the seven modes described earlier in this paper.

With the identification of the Lasswell Triad as the type of infrastructural invention required to deal comprehensively with complexity, hence with knowledge integration, the "good assumptions" presented earlier in this paper have been amplified to show the requirements of good practice, as dictated by complexity.

10. THE LAST WORD

An effort has been made, in this paper, to emphasize the necessity and feasibility of basing integrative studies on formalisms. The principal arguments in support of this idea basically reduce to conditions for adequate use of language by fallible human beings. Still, there will be those who will feel the necessity of rejecting both the proposal and the rationale for it.

There are some substantive reasons to reject this proposal. One good reason to reject it is that, even if it seems meritorious, there is no reason to suppose that it will be properly implemented by practitioners.

- **The Prose-Crustes Practitioners.** The age-old story of the giant Procrustes, who fit every traveler to accommodate his bed, either by stretching the traveler or lopping off parts, applies to insisting on associating perception and description only with prose. There are those who wish to represent everything exclusively in prose, or perhaps in prose augmented by "landscape-type" artwork. There are certainly instances where such

²² John N. Warfield (1994): *A Science of Generic Design: Managing Complexity Through Systems Design*, Second Edition, Ames, IA: The Iowa State University Press (first published in 1990 in two volumes in Salinas, CA: Intersystems).

²³ J. N. Warfield and A. Roxana Cárdenas (1994), *A Handbook of Interactive Management*, Ames, IA: The Iowa State University Press.

representations are very appropriate, but they tend to be limited to fiction and/or entertainment; rather than domains where substantive integration of substantive knowledge components is desired.

- **The Narrow-Circle Technocrat.** The narrow-circle technocrat wishes to make representations mostly in either mathematics or floating graphics or a combination thereof. The effect of this is generally to inhibit communication, or close it off altogether, but it does often have the effect of protecting the "rice bowl".

Still the Procrustean behavior is present there as well. The narrow-circle technocrat often makes a very poor choice of formalism from which to create a set of associations. The operational features of a formalism are adopted and often heavily promoted, but without satisfying the axiomatic basis of the formalism as a necessary condition for its selection and use. For example, some use "systems dynamics" for representing very wide-scope situations, when there is no evidence that such situations satisfy the axiomatic conditions required to apply the (non-interpretable) formalism. This practice gives formalisms a bad name.

- **The Odd Couple.** Because of the Procrustean behavior that is shared by the prose-minded individual (typically with a liberal arts-orientation) and the technocrat (typically with an engineering, business, or applied-science orientation); these two groups, in effect, collaborate as an unofficial cartel to work (perhaps unknowingly) against effective communication.
- **The Inherent Difficulty.** Without regard to the cultural features of persons who populate a unity, one can say that there is an inherent difficulty in creating an adequate, understandable structural basis for a unity. If it were not so, the unities would be much better understood than they are present. All it takes to deny an adequate representation of a unity is the inherent difficulty, accompanied by even a modest adherence to representation in the ordinary communication vehicles of the genre.

Faced with this situation, the most powerful argument that can be brought to support the proposals advanced here may be that the ease of integrating two sciences is greatest at the level of the foundations, where opportunities for inconsistency and error are the least, because of the very small population of foundational ideas. And the available technological support for doing such integration in the complex, problematic situations is demonstrably effective.

TWENTY LAWS OF COMPLEXITY:

Studies in the Abuse of Reason

Studies in the Abuse of Reason

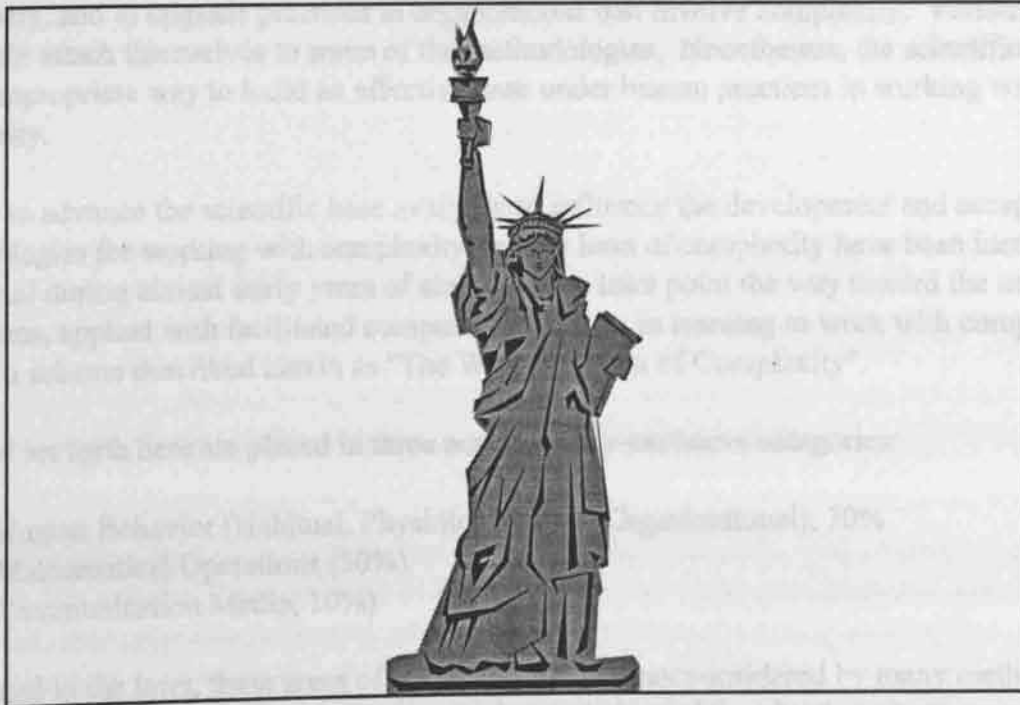
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ABSTRACT



"Sum, ergo cogito"

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INTRODUCTION

TWENTY LAWS OF COMPLEXITY: Studies in the Abuse of Reason

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ABSTRACT

Many methodologies are presently advocated as ways to advance human understanding of complexity, and to upgrade practices in organizations that involve complexity. Various schools of thought attach themselves to some of the methodologies. Nonetheless, the scientific method is still an appropriate way to build an effective base under human practices in working with complexity.

In order to advance the scientific base available to influence the development and acceptance of methodologies for working with complexity, twenty laws of complexity have been identified or discovered during almost thirty years of study. These laws point the way toward the use of formalisms, applied with facilitated computer assistance, in learning to work with complexity; through a scheme described herein as "The Work Program of Complexity".

The laws set forth here are placed in three non-mutually-exclusive categories:

- Human Behavior (Habitual, Physiological, and Organizational), 70%
- Mathematical Operations (30%)
- Communication Media, 10%)

As invoked in the laws, these areas of study typically are not considered by many methodology developers or by many systems theorists, which may help explain why these laws are so frequently overlooked in practice.

Each law is presented in a common format called a "Brief" which gives the name of the law, its origins, references (when available), the statement of the law, and an interpretation of the law. A structure is offered that shows how some laws inform other laws.

These laws underpin a previously-developed science of generic design, and a learning and system design concept called "Interactive Management".

INTRODUCTION

Prolonged study of complexity (1968 until now) has made it possible to detect or to compose 20 Laws of Complexity, which are presented in this document. These Laws relate to organizations and human behavior somewhat as Newton's Law of Gravitation relates to flying. While Newton's Law would seem to say to the superficial observer that people cannot fly, its' real relevance to flying is to help clarify what had to be added to the human repertoire to make it possible for humans to fly. In much the same way, the Laws of Complexity help us learn why what we do poorly with limited repertoires has to be augmented by a more extensive repertoire in order to be able to overcome or to manage complexity.

Newton's Law of Gravitation also shed light on the details of what was required. While no clear definition of an aircraft or balloon or helicopter or space ship was provided in Newton's Law, a thoughtful inventor, oriented toward design, could take advantage of what the Law said to establish the general nature of what would be needed in order for the human being to be able to fly.

At the same time, not all observers were able to make the connection. Lord Kelvin, who made significant contributions to the development of technology, may have been so obsessed with perceived constraints and the predominance of quantification that it became impossible for him to conceive that a person could fly. He has been quoted as saying that x-rays would prove to be a hoax, that radio wouldn't work, and that things heavier than air could never fly.

Continuing with the analogy, there have been people who tried to fly with the help of machines, and dropped to their death, allowing their enthusiasm for adventure and their willingness to experiment to dominate any systematic study and careful design of what might be expected to perform well.

At this point the analog to the evolution of human capability to work with complexity starts to lose some of its power. The ability of Thomas Edison to discover (by continued brute-force experiment, relatively uninformed by knowledge of materials science) a material that could support electrical generation of light in a container which could protect the material from various forms of degeneration, is not likely to be matched by a brute-force approach to complexity. Still many such brute-force attempts go on today but, unfortunately, their incidental impact is not limited to the destruction of small samples of matter. Instead they frequently create major disasters for large numbers of human beings. Even if they do not, they may often prevent wonderful things from happening by wasting resources.

If these Laws of Complexity are accepted as fact, but not as constraints that will necessarily forever make impossible human intellectual growth and its exploitation in making life better, the work devoted to finding and articulating them will have been very worthwhile. If they are regarded as major sources of insight into how to get constructive human behavior, so much the

better.

The Laws are related to my evolving, fledgling Science of Complexity through the matrix that appears in **Figure 1**, which is intended to relate human behavior to the work components required to comprehend the complex and to cope with it. This matrix is indexed by two sets. One set is called "The Work Program of Complexity". This Work Program involves the four components:

- **Description.** A description of the problematic situation is developed to make possible a relatively common understanding of it among those to whom the situation is relevant, and who may take action to improve that situation.
- **Diagnosis.** A diagnosis of the problematic situation, founded in and referenced to its description, lays the basis for design, i.e., for prescription of what is needed and should be done in order to correct the dysfunctional aspects found in the diagnosis.
- **Design (Prescription).** A design, intended to correct the problematic situation, founded in the description, and justified by the diagnosis, is carried out in order to specify rigorously the program required to make the correction. This design must be communicable, typically, to a wide variety of stakeholders, with a wide variety of backgrounds, and with strong distinctions among their respective languages and knowledge bases.
- **Implementation.** A program involving many people is carried out to implement the design, in the light of the consensual description and diagnosis.

To be successful, this Work Program must be both understood and feasible to carry out. To help assure that it will be both feasible and understood, the behaviors required to carry out the Work Program are conceived in the light of the Laws of Complexity. The four Behavioral Components which index the Behavior-Outcomes matrix in the vertical direction, must each be examined to discover what is **not** feasible and what **is** feasible, and what arrangements are necessary in order to sustain the feasibility throughout the Work Program of Complexity.

To help orient the considerations, those Laws of Complexity that are particularly relevant to various intersections of the Behavior Components with the Work Program of Complexity are shown in the various cells of the matrix.

Laws that do not appear in particular cells may still be very relevant thereto. What is shown here is where **heavy emphasis** must be given. The portrayal of emphasis does not deny the importance of systematic testing of **every** cell in the light of **every** Law of Complexity. Much of this testing has been done already (though it should be repeated, at least in miniature by potential participators) in the development of A Science of Generic Design and in the presentation of the management system described in the Handbook of Interactive Management. Citations for both of these books, and others, are given in detail in the set of Briefs included in this document.

OUTCOMES				
B E H A V I O R	DESCRIPTION	DIAGNOSIS	PRESCRIPTION (DESIGN)	IMPLEMENTATION
	<ul style="list-style-type: none"> ■ Limits ■ Triadic Necessity & Sufficiency ■ Universal Priors 	<ul style="list-style-type: none"> ■ Success & Failure ■ Universal Priors 		<ul style="list-style-type: none"> ■ Gradation ■ Validation
	<ul style="list-style-type: none"> ■ Limits ■ Triadic Compatibility ■ Small Displays 		<ul style="list-style-type: none"> ■ Requisite Parsimony ■ Requisite Saliency 	
	<ul style="list-style-type: none"> ■ Limits ■ Uncorrelated Extremes 	<ul style="list-style-type: none"> ■ Inherent Conflict ■ Structural Underconceptualization ■ Diverse Beliefs 	<ul style="list-style-type: none"> ■ Requisite Variety ■ Induced Groupthink 	
	<ul style="list-style-type: none"> ■ Limits ■ Organizational Linguistics ■ Vertical Incoherence 	<ul style="list-style-type: none"> ■ Forced Substitution ■ Precluded Resolution ■ Vertical Incoherence 		
PROCESS				
INDIVIDUAL				
GROUP				
ORGANIZATIONAL				

Fig. 1. BEHAVIOR--OUTCOMES MATRIX (Understanding The *Work Program of Complexity*)
showing which Laws of Complexity relate strongly to which combination of behavior and outcome.

FIVE SCHOOLS OF THOUGHT

The prevalence of complexity is a fact of life in virtually all aspects of system design today. Five schools of thought concerning complexity seem to be present in areas where people strive to gain more facility with difficult issues:

- **Interdisciplinary "approaches" or "methods"** (fostered by the Association for Integrative Studies, a predominantly liberal-arts-faculty activity)
- **Systems dynamics** (fostered by Jay Forrester, Dennis Meadows, Peter Senge, and others often associated with MIT, i.e., The Massachusetts Institute of Technology, located in Cambridge, Massachusetts)
- **Chaos theory** (arising in small groups in many locations)
- **Adaptive Systems Theory** (predominantly associated with the Santa Fe Institute, but beginning now to be associated with many American schools of business or management)
- **The Structure-Based School** (developed by the author, his colleagues and associates)

Figure 2 summarizes the views of the author about these schools of thought. A key factor in comparing these schools of thought is the concept of "formalism"; i.e., an integrated system of signs having the property of being uninterpreted until associations are made with this system. For example, the formula $x = y/z$ is based in an integrated system of signs that we call "algebra", but this formula remains uninterpreted until we assign specific concepts to it, such as: $x = I$; $y = E$, $z = R$; where I represents electrical current, E represents voltage, and R represents electrical resistance. When these associations are made, the original formula now is interpreted as "Ohm's Law". The application of this law to human understanding then not only incorporates the physical understanding derived from early experiments with electricity, but also the constraints attached to the signs coming from the mathematical construct that we call "algebra". By distinguishing the formalism from the associations and subsequent numerical assignments that are made to it, we hope to divorce from the assignments the validity that is generically attached to the formalism itself; insisting that the validity of the interpretation depends upon the validity of the associations and assignments. There is already far too much tendency to attach validity to interpretations involving numbers, simply because numbers themselves have widespread validity stemming from the formalism under which the numbers came into being.

FIGURE 2. SCHOOLS OF THOUGHT ABOUT COMPLEXITY

NAME OF SCHOOL	UNDERLYING FORMALISM	WHERE COMPLEXITY LIES
Cross-discipline (cd)	None	Unspecified
Systems Dynamics	Ordinary differential equations	In the system
Chaos Theory	Ordinary nonlinear differential equations	In the system
Adaptive Systems Theory	Partial differential equations	In the system
Structure-Based	Formal western logic, including set theory, theory of relations, digraph theory, lattice theory, boolean methods, and the algebra of partitions	in the mind [much of the foundational work is represented by the works of Peirce, Piaget, Polanyi, and Vickers.]

Each of the five schools appears to rest on a different type of formalism. The fact that the connections between the formalism and the school of thought are not always carefully laid out does not deny the existence and application of the formalism explicitly, or by analogy or metaphor, or in some other way.

It is not intended in this document to offer arguments for the first four listed schools of thought. Their advocates are quite experienced in doing so, and their views appear in many literatures, frequently in a very prominent way. The reasons for introducing them here are:

- to help the novice in this area appreciate that there are views which are not consistent with the school of thought reflected in the Laws of Complexity;
- to acknowledge the existence of such incompatible views, and to explain how the school of thought proposed here is different; and
- to provoke more thought on what complexity is.

The vast majority of the proponents of Systems Dynamics, Chaos Theory, and Adaptive Systems Theory hold a common point of view about complexity: that **complexity is an aspect of the systems which they explore.**

In contrast, the school advocated here is given the name: **Structure-Based School.** This school of thought holds that complexity finds its locus in the human mind, rather than in whatever the human is striving to comprehend.

This viewpoint is informed by, is consistent with, and draws inspiration from, several authors who, in one way or another, have contributed to the underlying philosophy. These authors include, in the temporal sequence in which their contributions first began to influence the developments:

- Charles Sanders Peirce
- Geoffrey Vickers
- Michael Polanyi
- Jean Piaget
- Alexander Pope
- Michel Foucault
- Friedrich A. Hayek

This list is far from exhaustive, and is chosen partly because of the variety reflected in their writings, as well as what I perceive to be the commonality and complementarity in their work.

In presenting the Laws, a particular learning sequence has been developed which, it is hoped, will make it easier to develop an integrated perspective on them. This sequence appears in *Figure 3*. Because this document is prepared for persons who are unfamiliar with the Laws, no attempt will be made at this point to justify the learning pattern shown.

CATEGORIES OF THE LAWS OF COMPLEXITY

Now that 20 Laws of Complexity have been discovered, the number of Laws has reached the point where it seems appropriate to place them in categories, which will help in describing and (hopefully) in understanding their nature.

Some of the Laws can reasonably be placed in more than one category. The following five categories have been chosen.

Type A. Three Categories Involving Human Behavior:

- **Habitual Behavior:** Constraints that human beings have imposed upon themselves, almost without thinking, evolved through prolonged activity.
- **Physiological Behavior:** Constraints on human behavior imposed by their physiology
- **Organizational Behavior:** Aspects of human behavior that involve their participation in organizations

Type B. One Category Involving Communication Media.

- **Linguistics of Communication:** Matters that affect media of human communication, including various aspects of human written or oral interactions

Type C. One Category Involving Mathematical Operations.

- **Mathematical Determinations:** Laws arrived at by mathematical operations, whether theoretical or empirically-based, or both

In principle, a few of these laws could be abolished over time, if habitual and organizational behavioral practices were adequately changed. Unless, and until, they are, the laws will stand.

Table 1 shows which laws are assigned to which categories. Also shown there is the percentage of the laws that have a basis in behavior (70%), in media (10%), and in mathematics (30%). Since none of the laws is based in the so-called "hard sciences", it is reasonably clear why technologists are unlikely to appreciate these laws, and are likely to make arbitrary judgments (often efficiency-based) that encroach on the domain of these laws.

THE REVOLVING DOOR TO ENLIGHTENMENT

Omar Khayyam (mathematician and astronomer, 1048-1122), speaking through the voice of Edward Fitzgerald (1809-1883), vented his frustration stemming from his attempts to get understanding, as follows:

"Myself when young did eagerly frequent
Doctor and Saint, and heard great argument
About it and about: but evermore
Came out by that same door where in I went."

The late contemporary French philosopher and chairman of the history of systems of thought at the Collège de France, Michel Foucault (1926-1984), in his masterpiece on the "archaeology of knowledge", believed (as described by D. W. Harding)

"that our own current intellectual life and systems of thought are built on assumptions profoundly taken for granted and not normally exposed to conscious inspection, and yet likely in time...to be discarded."

In amplifying that view, Foucault states that:

"The manifest discourse, therefore, is really no more than the repressive presence of what it does not say; and this 'not-said' is a hollow that undermines from within all that is said."

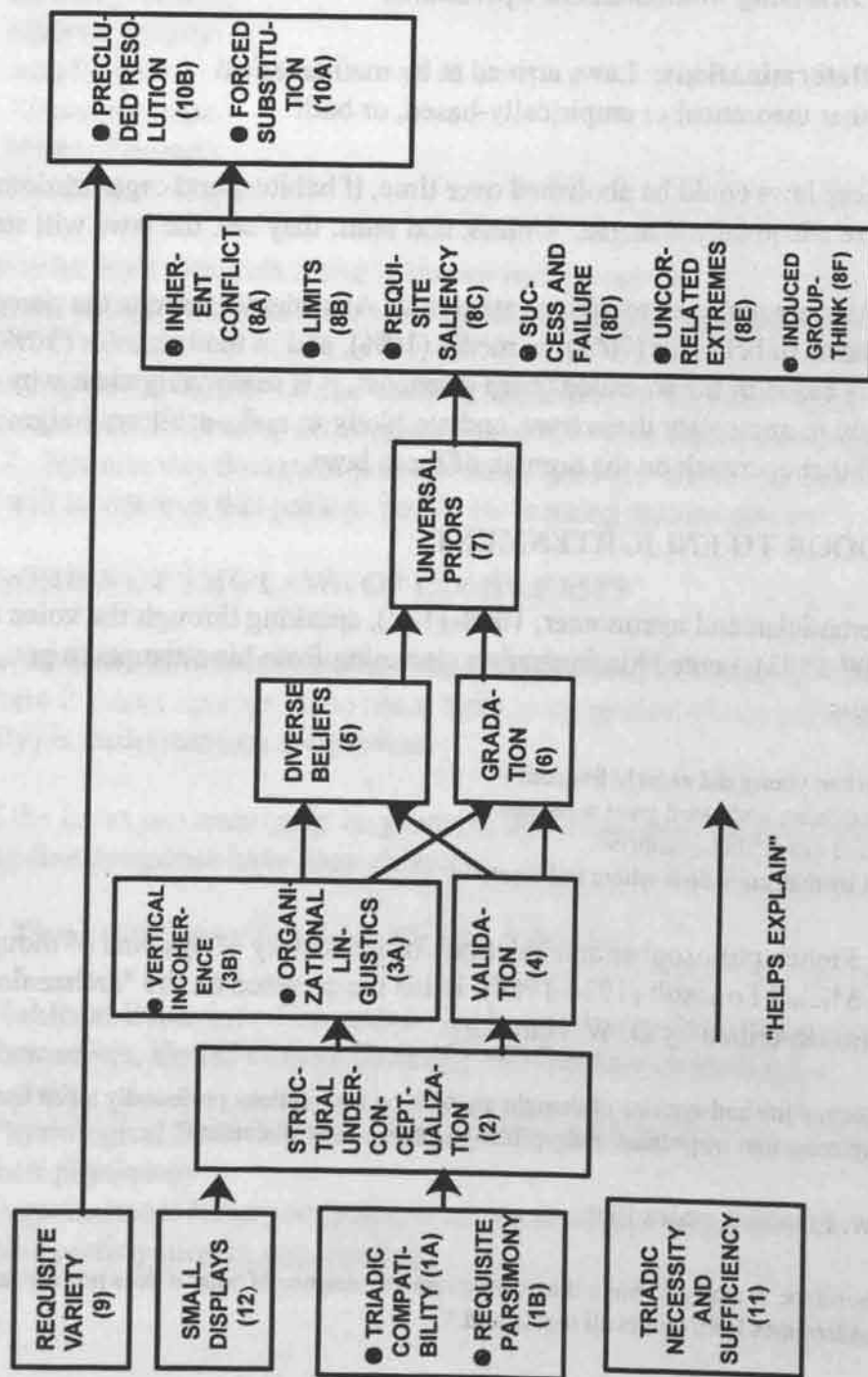


FIGURE 3. INTERACTIONS IN INTERPRETING LAWS OF COMPLEXITY. If a Law appears on the left of and connects to a Law to its right, then an understanding of the Law on the left is helpful in developing an understanding of the Law on the right. Laws that appear in the same box (with bullets in front of each Law in the box) are helpful in understanding all of the other Laws in the same box (they are in a "cycle").

TABLE 1. CATEGORIES OF LAWS OF COMPLEXITY:

LAW OF IIIIIII	BEHAVIORALLY-BASED (70%)			MEDIA- BASED (10%)	MATHEMA- TICALLY BASED (30%)
	HABITUAL	PHYSIO- LOGICAL	ORGANIZA- TIONAL		
1A Triadic Compatibility		X			X
1B Requisite Parsimony		X			
2 Structural Underconceptualization	X	X		X	
3A Organizational Linguistics			X		
3B Vertical Incoherence			X		
4 Validation					X
5 Diverse Beliefs	X				
6 Gradation					X
7 Universal Priors	X				
8A Inherent Conflict	X				
8B Limits		X			
8C Requisite Saliency	X	X			
8D Success and Failure					X
8E Uncorrelated Extremes					X
8F Induced Groupthink	X		X		
9 Requisite Variety					X
10A Forced Substitution			X		
10B Precluded Resolution			X		
11 Triadic Necessity and Sufficiency					X
12 Small Displays	X			X	

It is none too early to try to begin to correct the shortcomings in our knowledge that stem from bad ("not-said") assumptions, uncritically accepted and propagated, especially in academia. Too much is at stake. Yet, such acceptance seemingly continues its relentless advance, compounded by technologies that typically show little friendliness to their users.

The twenty Laws to be described are intended to be responsive to Omar's complaint.

BRIEFS OF THE LAWS OF COMPLEXITY

In this document, the Laws of Complexity that have been discovered to date are presented in the form of "briefs". A Brief is given for each, showing the name of the Law, its origins, references to relevant literature, the statement of the Law, and its interpretation.

There is a dual logic involved in this arrangement. From one point of view, the brief of the Law should be given before it is applied to particular situations. From another point of view, application of the Law to a specific situation sheds light on how to perceive it when it is formally presented.

As presented here, the Laws appear in a specific learning sequence, this being the sequence that was shown in Figure 3. This sequence is believed to support efforts to learn the set of Laws.

LAWS OF COMPLEXITY: BRIEF 1A

NAME OF LAW: Triadic Compatibility

ORIGIN(S) OF LAW:

Empirical, (Miller, Simon); Mathematical [Applied Lattice Theory], (Warfield)

REFERENCES:

G. A. Miller (1956), "The Magical Number Seven, Plus or Minus Two: Some Limitations on Our Capacity for Processing Information", *Psychology Review* 63(2), 81-97.

H. A. Simon (1974), "How Big is a Chunk?", *Science* 183, 482-488.

J. N. Warfield (1988), "The Magical Number Three--Plus or Minus Zero", *Cybernetics and Systems* 19, 339-358.

STATEMENT OF LAW:

■ The human mind is compatible with the demand to explore interactions among a set of three elements, because it can recall and operate with seven concepts, these being the three elements and their four combinations; but compatibility cannot be presumed for a set that both has four members and for which those members interact.

INTERPRETATION OF LAW:

This Law expresses both a human limitation and a human capability. The limitation suggests that human beings cannot process interrelationships among sets of factors, issues, objects, or ideas in general, if more than three components are involved. The reason set forth is that the mind is incapable of recalling into its short-term memory more than about seven items. (A set comprised of 3 elements and the four interacting combinations of them will consist of seven members.)

A way to show respect for this limitation is to determine that whenever decisions are to be made that can benefit from awareness of interactions, it will be advisable to choose and apply a strategy that recognizes the impact of this limitation.

This limitation should also persuade individuals that intuitive decision-making, carried out without careful analysis, is likely to produce bad decisions and bad outcomes when complexity is present.

The capability that allows us to process interrelationships among three factors, issues, objects, or ideas should encourage us to begin to develop a facility for working with sets of three items. More specifically, it would be advisable to build up a repertoire of sets of three items that are representative of decision-making situations, and develop skill at working with these sets.

It might be well to remember that many situations in life have been approached as though there were a dichotomy involved. Instead of allowing our thinking to be limited to dichotomies, we should be encouraged to move to trichotomies as a way of becoming more flexible in thought and action, wherever appropriate.

We may also be persuaded that documentation is much more valuable than might be thought, especially if the documentation takes the form of representing systems of interactions involving more than three interacting members.

When we have developed patterns of interrelationships as documentation, we may work to develop the skill of reviewing and amending such patterns. Moreover, we may begin to see merit in group development of interrelationship patterns, since there is little in the capability to work with three items that suggests an overwhelming power of a single individual to construct patterns of interrelationship that are representative of actual conditions or systems, or of contemplated conditions or systems.

The limitation to interactions among three items suggests a very serious limitation on creative ability as might be reflected in design of complex systems. Ad hoc designs, arrived at in ordinary conversational modes (as, for example, in governmental bodies or committees) might be looked upon as unlikely to be of high quality, and likely to produce bad outcomes.

LAWS OF COMPLEXITY: BRIEF 1B

NAME OF LAW: Requisite Parsimony

ORIGIN(S) OF LAW:

This law is based on the dynamics of interpreting and learning implied by the Law of Triadic Compatibility. The Law is prescriptive, with the aim of allowing enough time for sequentially-presented information to be interpreted in terms of the interactions, and to allow enough listening time to help ensure that the information is remembered.

REFERENCES:

None

STATEMENT OF LAW:

■ Every individual's short-term brain activity lends itself to dealing simultaneously with approximately seven items (a number that is reached with three basic items and four of their joint interactions) [see the Law of Triadic Compatibility]. Attempts to go beyond this scope of reasoning are met with physiological and psychological Limits that preclude sound reasoning. For a given designer, there is some number K_d that is characteristic of that designer which typically is chosen from the set $\{5,6,7,8,9\}$ that represents the Limit of that designer's short-term idea-processing capability. If a design methodology requires a designer to cope intellectually at any one time with some number of concepts K_c , then

- i) If $K_c < K_d$, the designer is underburdened, being uninfluenced by the Law of Requisite Parsimony, since the designer is operating in a Situation that exhibits the Requisite Parsimony, through regulation of the rate of flow of information to the designer as the designer engages in the design process
- ii) If $K_c = K_d$, the designer is operating at the Limit of reasoning capability
- iii) If $K_c > K_d$, the designer is overburdened and no reliance can be placed on the designer's decisions.

INTERPRETATION OF LAW:

If the Law is **not** violated, it has no impact. If it is violated, it can be confidently predicted that the design Target (i.e., whatever description or product the individual or group seeks to achieve) will embody bad outcomes that are beyond the control of the designer, because the design process did not exhibit the Requisite Parsimony, but instead allowed the rate of flow of information to the designer to exceed processing capacity.

It may be questioned why designs have succeeded in the past without overt adherence to this requirement. Design Targets vary significantly in their scope. If the Law of Requisite Parsimony is being unknowingly violated, one would expect that the impact would be revealed in the failure of large system designs. This is precisely what is being observed all around the world.

Those who deny the validity of and those who doubt this Law must accept the burden of providing other explanations for failures. The often-rendered explanation "operator error" may often, itself, reflect the same fundamental cause to which this Law responds in terms of the design process.

LAWS OF COMPLEXITY: BRIEF 2

NAME OF LAW: Structural Underconceptualization

ORIGIN(S) OF LAW:

Empirical, Mathematical logic

REFERENCES:

J. N. Warfield (1979) "Some Principles of Knowledge Organization", IEEE Transactions on Systems, Man, and Cybernetics, June, 317-325.

J. N. Warfield (1991) "Underconceptualization", in Mutual Uses of Cybernetics and Science, Special issue of Systemica: Journal of the Dutch Systems Group (R. Glanville and G. de Zeeuw, Eds.), Amsterdam: Thesis Publishers, 415-433.

J. N. Warfield (1994) A Science of Generic Design: Managing Complexity Through Systems Design, Second Edition, Ames, IA: Iowa State University Press (first edition, Salinas, CA: Intersystems, 1990).

STATEMENT OF LAW:

■ No matter what the complex issue, and no matter what the group involved in its study, the outcomes of ordinary group process (i.e., process in which computer support for developing the formal logical structure of the issue is lacking) will be structurally underconceptualized (as evidenced, for example, by the lack of delineation of the cycles and of any structural connections among them).

INTERPRETATION OF LAW:

A proper interpretation of this Law requires an understanding of the fundamental nature of structure. The term "structure" is widely used by economists in very loose way, virtually as a semi-metaphor. This widely-practiced usage simply serves to put a veneer on top of what can be very precisely defined. A proper interpretation of structure refers to how individual substantive components of information or knowledge are related.

To understand the foundations of relationships, one needs to know something about the history of the development of what is called "the theory of relations" or "the logic of relatives". The most foundational work done in this area was carried out by a British professor, Augustus De Morgan, who published his treatise in the year 1847. Listen to how his work was described (sometime around the year 1867) by America's greatest philosopher, Charles Sanders Peirce:

"a brilliant and astonishing illumination of every corner and every vista of logic"

But the direct connection of De Morgan's work to the structure of information or knowledge did not become crystal clear until the publication of a book by Professor Frank Harary and two junior colleagues at the University of Michigan in 1965 [Frank Harary, R. F. Norman, and D. Cartwright, *Structural Models: An Introduction to the Theory of Directed Graphs*, New York, Wiley].

In this book, Harary showed that any given relation corresponds directly to a particular graphical structure; and that every relation corresponds to some form of directed graph ("digraph") (although the utility of such a correspondence seems limited to the so-called "transitive relations", a very large class).

Taking that information, Warfield showed in his 1976 book [*Societal Systems: Planning, Policy, and Complexity*, New York: Wiley] that the most general form of digraph representing a relation exhibited several attributes:

- A hybrid structure
- Exactly two distinctive prototypical substructural types in a hybrid structure identifiable as either (a) hierarchy or (b) cycle
- A numerical measure of the length of any hierarchical substructure
- A numerical measure of the length of any cycle substructure
- A numerical measure of the "width" of a hierarchy, giving a numerical meaning to "linear structure" as a hierarchy of width 1; and giving a numerical interpretation to the idea "breadth of relationship"
- A numerical measure of the structural complexity of a relationship based upon the structural features of the hybrid structure (and this measure of complexity has since been joined by several new ones discovered in recent years)

In that same work, Warfield presented a variety of algorithms for developing such structures with computer assistance, providing a methodology that allowed the structures of complex issues to be created by groups of knowledgeable people and, thereby, opening the way for the structure of knowledge to take its rightful place among the analytical and synthetic concepts available to people to analyze complex issues or systems, and to design such complex systems in a way that would make clear how the designs relate to the issues themselves, thereby eliminating the need for vagueness in the design of such systems as health care systems or systems for dealing with other public policy matters; as well as providing a similar benefit in the design of physical systems such as automobiles.

But in spite of these developments and the broad-ranging nature of the benefits that could be attained by taking advantage of them, only a relatively small number of people have learned about this area and have begun to take advantage of what is known.

In the laboratory work done by Warfield and his colleagues, a considerable amount of data was taken based on work done by numerous groups with a variety of complex issues. These data showed typical attributes of the structures developed. It was found that over 97% of all structures were hybrid structures (i.e., they contained at least one cycle).

The most evident proof of structural underconceptualization in dealing with complex issues and complex systems is the failure even to identify the cycles that are present in the structures. A lesser evidential point is that frequently the hierarchical substructures are not identified. The set of hybrid structures required to show the underlying structure of information is virtually never constructed. If and when the set is constructed, it may be superficially rendered (as in Senge's "archetypes") in non-operational form, leaving the actor to invent, without recommended processes, the more substantive and particular instances relevant to a given situation; which seemingly asks the actor to become a process inventor.

Hence the wide-ranging scope of the Law of Structural Underconceptualization. But it must be realized that structural underconceptualization always implies underconceptualization. The situation is as though a human body were presented without any skeleton. We would see a limp corpse with no definition of human shape. It is only the structural feature of the body that allows it to be erect or elongated, and provides the basis for its overall appearance.

How frightening can it be that in virtually every major public issue or virtually every large system design seen in our society, the structural descriptions are not even comprehended, and not made available for view and interpretation?

How disappointing and how demoralizing can it be that the latter is not being done, even though it is perfectly feasible to do it, to do it efficiently, and to do it in a responsible, high-quality way?

LAWS OF COMPLEXITY: BRIEF 3A

NAME OF LAW: Organizational Linguistics

ORIGIN(S) OF LAW: Empirical

REFERENCES: None

STATEMENT OF LAW:

■ **As an organization grows, linguistic separation grows both laterally and vertically in the organization. At the higher vertical levels, metaphors and categories become progressively disconnected from the relevant components at lower levels, leading to decisions based on perceived relations between categories that are not borne out by relations between the members of those categories.**

INTERPRETATION OF LAW:

Imagine that a group of people is formed by selecting several individuals from the human race at random. Then suppose that exhaustive information is obtained which will reveal what language components are shared by every single member of that group. It may be that one of the members came from a remote tribe in Australia, and another came from a similarly remote tribe in the mountains of Peru. It may be that there is virtually no language component that is shared by the group.

The term "linguistic domain" was applied by the Chilean scientist Maturana to describe the language commonality among a group of people.

It is easy to see that if a certain group effectively defines their linguistic domain, the extent of that domain will normally shrink as new members become attached to the group, unless some specific actions are taken to restore or enlarge the linguistic domain. Enlargement would require that every single member of the group take on the addition, whatever it might be, in order that an enlarged linguistic domain could be said to exist.

Now imagine a large organization which is hierarchically organized so that conversations mostly occur **within** rather than **across** organizational layers. Each one of these layers corresponds to a certain linguistic domain that holds within that layer. Yet as human turnover occurs in a layer the linguistic domain of that layer changes.

The maintenance of a linguistic domain relies on (a) usage of the existing domain to keep it at the forefront of each individual's usable language, and (b) upgrading of the domain every time a new member enters, in order to prevent its deterioration.

Since big organizations do virtually nothing to maintain even a single linguistic domain, it is inevitable that over time people will only be able to talk to one another knowingly in a given layer and then, only in the fractional terms that remain after the natural progressive deterioration that goes on in these domains.

But deterioration of linguistic domains is often less affected by change in the human makeup of the relevant groups than it is by changing technology. In many industries, technological change causes significant demands to be made to incorporate new terminology in a linguistic domain, yet the technological terminology is often so poorly defined or so foreign that assimilation of it into a given domain can only be done if the organization pays the price. The price that has to be paid is that time of the affected individuals must be dedicated to human interaction aimed at renewing and strengthening the linguistic domain.

But even if linguistic domains are strengthened in a few layers of a large organization, still another phenomenon becomes critical. What is being talked about in the lower levels of the organization are often highly detailed subjects, these subjects never being discussed at that level of detail in the higher levels of the organization. If there is going to be a linguistic connection between levels, one must recognize that the metaphors and categories (the high-level organizational language) have to have a strong correlation to the detailed information (the low-level organizational language), and that this correlation has to be sustained and renewed constantly in order to preserve meaningful communication across organizational boundaries.

Empirical observation of groups who work at different levels in organizations has shown that the relationships that high-level people construct and apply among metaphors and categories simply do not correlate with the lower-level ideas that high-level people assume are encompassed within those metaphors and categories. The result is that the decisions and actions taken at high levels in organizations often amaze the operating levels because they make so little sense and vice versa. The reason for the lack of sensibility is that both levels are operating in what might be called incongruous linguistic domains.

Until organizations understand the necessity for maintenance, renewal and cross-organizational development of linguistic domains, those ever-present trends that work against effective communication will continue to be the responsible for what appears to the external observer as organizational incompetence.

LAWS OF COMPLEXITY: BRIEF 3B

NAME OF LAW: Vertical Incoherence

ORIGIN(S) OF LAW: Empirical

REFERENCES:

Henry C. Alberts (1995), "Redesigning the United States Defense Acquisition System", Ph. D. Dissertation, Department of Systems Science, The City University, London, U. K.

A. Roxana Cárdenas and Jose C. Rivas (1995), "Teaching Design and Designing Teaching", in *Integrated Design and Process Technology* (A. Ertas, C. V. Ramamoorthy, M. M. Tanik, I. I. Esat, F. Veniali, and Taleb-Bendiab, Editors), IDPT-Vol. 1, 111-116.

Warfield, J. N. (1995), "SPREADTHINK: Explaining Ineffective Groups", *Systems Research* 12(1) 5-14.

STATEMENT OF LAW:

■ For any large organization that is unaware of this Law, there are invisible-but-potentially-discoverable Patterns of Vertical Coherence awaiting discovery; which when discovered, will show how key features of that organization are (a) many in number, (b) can be structured into categories that are much fewer in number, and (c) whose categories can be structured into areas that are again much fewer in number. The features include problems, available small-scale options for resolving the problems, and other element types yet to be discovered. This structure will be an "inclusion structure" from the class of Application Structural Types described in A Science of Generic Design.

INTERPRETATION OF LAW:

■ This Law relates to what I have called the "Alberts Pattern", based on work done first by Henry Alberts and later by Roxana Cárdenas and Jose Rivas.

Further elaboration of this Law indicates that the three levels in the Pattern can typically be correlated strongly with what have historically been called the Operational Level, the Tactical Level, and the Strategic Level; and those in turn can typically be correlated with Front-Line Management/Labor, Middle Management, and Top Management.

Still further elaboration comes from evidence that these three stratified levels are not adequately understood in organizations, and that many bad organizational decisions at each level come about because of this lack of understanding.

LAWS OF COMPLEXITY: BRIEF 4

NAME OF LAW: Validation

ORIGIN(S) OF LAW:

Philosophy of science, as originated by Charles Sanders Peirce.

REFERENCES:

Thomas A. Goudge (1969) The Thought of C. S. Peirce, New York: Dover.

Patricia S. Churchland (1986) Neurophilosophy: Toward a Unified Science of the Mind-Brain, Cambridge: MIT Press.

J. N. Warfield (1994) A Science of Generic Design: Managing Complexity Through Systems Design, Second Edition, Ames, IA: Iowa State University Press (first edition, Salinas, CA: Intersystems, 1990), p.58.

John Deely (1991) Basics of Semiotics, Bloomington: Indiana University Press.

STATEMENT OF LAW:

■ **The validity of a science depends upon substantial agreement within the scientific community of meaning at its highest grade, i.e., meaning attained through Definition by Relationship.**

INTERPRETATION OF LAW:

Many philosophers believe that they understand the concept of valid knowledge. The people that they like to refer to include Auguste Comte, Thomas Kuhn and Karl Popper. Others, who hear these people being named as the origins of the appropriate views about what constitutes valid knowledge are likely to accept their views without question, based on the assumption that the philosophers have adequately explored the presuppositions underlying the views of people such as Comte, Kuhn, and Popper.

In contrast, the mature philosophy of Charles Sanders Peirce presents a philosophy of science that is not consistent with any of the foregoing. Moreover, John Deely has clarified what is wrong with the popular view of scientific validity, and has made clear why the popular view that there exists observer-independent "objective knowledge", which has a higher quality than ordinary knowledge, is misbegotten.

To get a hearing, one must proceed as follows:

- Explain why the prevailing views are wrong (that takes quite a bit of time and argument)
- Explain what the appropriate views are (that requires quite a

bit of background from the listener, which most of them who are "college-educated" lack)

- Explain why the latter views are appropriate

Since that can't be done in a short space, we have to appeal to the reader and make a promise to the reader. The appeal is to suspend belief in the commonly-accepted ideas and take an interest in exploring another point of view. The promise is that the reader who will spend enough time studying the matter can get virtually all of the important ideas from the references given here.

LAWS OF COMPLEXITY: BRIEF 5

NAME OF LAW: Diverse Beliefs

ORIGIN(S) OF LAW: Empirical

REFERENCES:

J. N. Warfield (1994) A Science of Generic Design: Managing Complexity Through Systems Design, Second Edition, Ames, IA: Iowa State University Press (first edition, Salinas, CA: Intersystems, 1990). See empirical data in Appendix 5.

J. N. Warfield (1991) "Complexity and Cognitive Equilibrium: Experimental Results and Their Implications", Human Systems Management 10 (3), 195-202. Reprinted as Chapter 5 in Conflict Resolution Theory and Practice: Integration and Application, Dennis J. Sandole and Hugo van der Merwe (Editors), Manchester, U. K.: Manchester University Press, 1993, 65-77.

J. N. Warfield (Editor) (1993) An Interactive Management Workshop on the Variant Design Process: RRM Joint Application Development (JAD) Dearborn, MI: Ford Motor Company Research Laboratory, June 18. (Distributed by Dr. Scott M. Staley, P. E.).

Warfield, J. N. (1995), "SPREADTHINK: Explaining Ineffective Groups", Systems Research 12(1) 5-14.

STATEMENT OF LAW:

- Whatever the group, whatever the complex issue being considered by the group, at the outset of group consideration of the issue, the individual members of the group will have quite diverse beliefs about the issue; and the probability is high that this situation will remain undiscovered and uncorrected, in the absence of a group learning experience using a methodology whose power to produce the necessary learning has been scientifically validated.

INTERPRETATION OF LAW:

In order for people to share a common point of view about a complex issue, several conditions must be met. The age-old philosophical Doctrine of Necessity underpins this idea:

■ **People must all share the same linguistic domain, in order that they can even conceive and express jointly and sincerely the same point of view**

But in complex areas, empirical evidence shows that people do not share an adequate linguistic domain, and frequently cannot even understand the initially-expressed points of view of others because they lack the substantive background knowledge or experience to do so. If they do not even share a common meaning of a critical word or phrase, they will not be able to express any shared point of view that they might hold, or even test whether they hold a shared point of view.

Even in the instances where they do share the same linguistic domain (which our research shows to be a rare situation, much rarer than almost anyone would likely believe until an opportunity is made available to observe appropriate human interactions), some believe that dramatic differences of opinion are a consequence of very different value orientations of individual people. But consider this. If people do not share a linguistic domain that is broad enough to enable them to express and share a common point of view, it will never be possible even to determine the existence or relevance of the influence of presupposed different value orientations. Therefore, even if the proponents of the differing values theory are correct, there is no way for them to establish their correctness in the absence of prior conditions.

Since the evidence of lack of sharing an adequate linguistic domain is compelling, one must give credence to the former. But even if this lack is discounted, the empirical evidence shows very clearly the absence of shared belief among groups of people who are supposedly knowledgeable in areas. So whatever the reason for this absence, the Law stands as an empirical fact.

This Law should compel a certain kind of behavior on the part of leaders who see value in developing a shared point of view. The kind of behavior that is required is to create conditions whereby the linguistic domain of that group of individuals whose diversity of views creates unmanageable or ineffective organizational conditions is enlarged to the point where it becomes feasible to enunciate and share a point of view.

If the leadership is unable or unwilling to do this, at least the leadership should recognize the value in knowing that virtually all individuals in the pertinent group have quite diverse beliefs about any complex issue. The potential benefit that may be seen by a leader is to enter the policy or action vacuum and promote one's own point of view based on the held authority. The potential dysbenefit that might be seen by a leader is that the leader is usually no different from any other of the relevant individuals. The leader's views are just as likely to be unsatisfactory as those of any of the others.

LAWS OF COMPLEXITY: BRIEF 6

NAME OF LAW: Gradation

ORIGIN(S) OF LAW: Theory of Relations: Inclusion Relation.

REFERENCES: None

STATEMENT OF LAW:

- Any conceptual body of knowledge can be graded in stages, such that there is one simplest stage, one most comprehensive stage (reflecting the total state of relevant knowledge), and intermediate stages whose content lies between the two extremes.
- The Corollary of Congruence. The first Corollary to this Law asserts that the class of situations to which a conceptual body of knowledge may apply, in whole or in part, likewise may be graded according to the demands that individual situations can reasonably make upon the body of knowledge. This is called the Corollary of Congruence, because it relates to the congruence between the Design Situation and Target with a restricted grade of the Generic Design Science that is called into play in the specific case. Clearly the designer is not required to uncover every detail of relevance, no matter what the cost. When in doubt, a conservative posture will call for erring on the side of the higher grade.
- The Corollary of Diminishing Returns. The second Corollary to this Law is the existing economic Law of Diminishing Returns, which states that the application of a body of knowledge to a Design Situation should be made through that stage at which the point of diminishing returns to the Situation (as opposed to only the user) is reached. This is called the Corollary of Diminishing Returns, and it highlights a major responsibility of the designer to make judgments about when this point is reached. Once again, a conservative posture will call for erring on the side of the higher grade.
- The Corollary of Restricted Virtual Worlds. The third Corollary to this Law states that the identification of the stage at which diminishing returns to the situation is reached normally requires the integration of the Virtual Worlds of the affected parties in the situation in relation to the dimensions of the situation. This is called the Corollary of Restricted Virtual Worlds, and it reflects the need for a global point of view in making the kinds of judgments that are required to achieve the appropriate congruence of gradation.

INTERPRETATION OF LAW:

The importance of this Law to the Science of Generic Design lies in the guidance that it provides to the designer concerning how to perceive any particular Design Situation with respect to the Science. In this respect, one notes that design Targets may range from very small, limited-scope

Targets to very large, broad-scope Targets.

It is **not** reasonable to take as a criterion for Generic Design Science that all of its Theory and all of its Methodology should be demonstrably required for all design activity. On the contrary, such a Science would be too brittle for use. The Law of Gradation overtly recognizes that Design Situations and Design Targets are themselves graded according to a variety of descriptions, not all of which can be foreseen. Accordingly, the Science of Generic Design should be applied judiciously, extracting from it one of its stages that is most appropriate for the particular Design Situations and Design Target.

The word "generic" does **not** mean "always required". What it **does** mean is "covering the set of gradations of Design Situations and Targets as a whole, without overlapping the applicable Specific Design Science; but subject to judicious restriction commensurate with the grade of the Design Situation or Design Target in any particular instance."

It is **not** the function of a Science of Generic Design to provide a recipe appropriate to every Design Situation. It is the function of such a Science to actuate the designer's professional responsibility to assess and correlate the gradation in the Situation and Target against the total sweep of the Generic Design Science, and to choose that restricted version of the Science which will be used openly, rather than to accept subliminally a restricted version that leads to underconceptualization of the Design Situation and the Design Target. It is the further function of the Generic Design Science to provide the means of documentation consistent with what the Design Situation requires.

LAWS OF COMPLEXITY: BRIEF 7

NAME OF LAW: Universal Priors

ORIGIN(S) OF LAW: Empirical

REFERENCES:

J. N. Warfield (1994) **A Science of Generic Design: Managing Complexity Through Systems Design**, Second Edition, Ames, IA: Iowa State University Press (first edition, Salinas, CA: Intersystems, 1990). See pages 16-18 and Chapter 2.

STATEMENT OF LAW:

■ The human being, language, reasoning through relationships, and archival representations are universal priors to science. (I.e., there can be no science without each of them.)

INTERPRETATION OF LAW:

- The Doctrine of Necessity. The validity of this Law can be established using what is called the Doctrine of Necessity. This Doctrine holds that, independent of the particular attributes of B, if A is necessary in order for B to exist, then A is a prior of B. (The word "prior", used as a noun, fills a need that no other word quite satisfies.) The test of the necessity of each of the four factors mentioned is to imagine that they are withdrawn, and then inquire as to whether in their absence a science is possible.
- The Human Being. Imagine first, that there were no human beings. Accepting the common evidence that human beings are the producers and the only producers of science, then it must be that the human being is a Universal Prior to Science.
- Language. Imagine next that no language were available. Since all of science consists of language, and nothing other than language, there can be no science without language.
- Reasoning Through Relationships. Suppose now that there is no reasoning through relationships. Since all organization of information is through relationships arrived at by reasoning, there can be no organization of knowledge without it. But science is organized knowledge, hence both language and reasoning through relationships are Universal Priors to Science.
- Archival Representation. The human being, language, and reasoning through relationships all can exist and persist without any archival representation, the organization being in the mind. It might, therefore, be argued that these three are sufficient, and that archival representation is not required in order for organized knowledge and, therefore, science to exist. But science depends upon widespread consensus, and library after library attests to the critical importance of archival representation in gaining the necessary widespread understanding and consensus upon which acceptance as science depends.
- Absence of Foundations. Overt recognition of the status of the Universal Priors to Science should bury the modest movement to assert that there are no foundations to (at least some) sciences. On the contrary, what is seen here not only states that there are some, but there are some that are foundations to all science. If one is to distinguish one science from another, it may be through finding unique foundations for a particular science that can and must be integrated with the Universal Priors to establish the decision-making basis for the particular science.
- Diminution of Universal Priors. One obvious, but misguided, way to try to provide distinctiveness to the foundations of a science is to lay the Universal Priors on the operating table, and to diminish them to shadows of their identity, while retaining slices of them. Thus the human being may be fractionated into an economic entity, a social entity, or other one-dimensional entity such as political, athletic, biological, etc., or through a role such as observer of nature. Language may be diluted by failure to establish and enforce the definitions of

its components, and reasoning through relationships may be diluted both by blurring the definitions of the relationship terms and by disguising patterns of relationship. The latter can occur naturally because of the linear sequential nature of prose, which does not lend itself to portraying patterns. Archival representations may themselves be so diluted by the emaciation of the other three Universal Priors as to be helpless to offer any assistance in searching for Referential Transparency.

LAWS OF COMPLEXITY: BRIEF 8A

NAME OF LAW: Inherent Conflict

ORIGIN(S) OF LAW: Empirical

REFERENCES:

J. N. Warfield (1994) A Science of Generic Design: Managing Complexity Through Systems Design, Second Edition, Ames, IA: Iowa State University Press (first edition, Salinas, CA: Intersystems, 1990). See empirical data in Appendix 5.

J. N. Warfield (1991) "Complexity and Cognitive Equilibrium: Experimental Results and Their Implications", Human Systems Management 10 (3), 195-202. Reprinted as Chapter 5 in Conflict Resolution Theory and Practice: Integration and Application, Dennis J. Sandole and Hugo van der Merwe (Editors) (1993), Manchester, U. K.: Manchester University Press, 65-77.

J. N. Warfield (Editor) (1993) An Interactive Management Workshop on the Variant Design Process: RRM Joint Application Development (JAD) Dearborn, MI: Ford Motor Company Research Laboratory, June 18. (Distributed by Dr. Scott M. Staley, P. E.).

Warfield, J. N. (1995), "SPREADTHINK: Explaining Ineffective Groups", Systems Research 12(1) 5-14.

STATEMENT OF LAW:

■ No matter what the complex issue, and no matter what the group involved in its study, there will be significant inherent conflict within the group stemming from different perceptions of the relative significance of the factors involved in the complex issue.

INTERPRETATION OF LAW:

The interpretation of this Law is essentially the same as that for the Law of Diverse Beliefs. The latter offers an explanation for the Law of Inherent Conflict. Because the beliefs are diverse,

there is inherent conflict within the group. The two Laws mentioned here are complementary and can often be seen as a composite that could be called the Law of Diverse Beliefs and Inherent Conflict. Nevertheless it is believed that the modest redundancy involved is not adequate justification to repeal the decision to present the two Laws separately. Each Law offers its own unique point of view.

In order for people to share a common point of view about a complex issue, and thereby avoid conflict on that issue, several conditions must be met. The Doctrine of Necessity underpins the idea that one condition is:

■ **People must all share the same linguistic domain, in order that they can even conceive and express the same point of view**

But in complex areas, empirical evidence shows that people do not share an adequate linguistic domain, and frequently cannot even understand the initially-expressed points of view of others because they lack the substantive background knowledge or experience to do so. If they do not even share a common meaning of a critical word or phrase, they will not be able to express any shared point of view that they might hold, or even test whether they hold a shared point of view.

Even in the instances where they do share the same linguistic domain (which our research shows to be a rare situation, much rarer than almost anyone would likely believe until an opportunity is made available to observe appropriate human interactions), some believe that dramatic differences of opinion are a consequence of very different value orientations of individual people. But consider this. If people do not share a linguistic domain that is broad enough to enable them to express and share a common point of view, it will never be possible even to determine the existence or relevance of the influence of presupposed different value orientations. Therefore, even if the proponents of the differing values theory are correct, there is no way for them to establish their correctness in the absence of prior conditions.

Since the evidence of lack of sharing an adequate linguistic domain is compelling, one must give credence to the former. But even if this lack is discounted, the empirical evidence shows very clearly the absence of shared belief among groups of people who are supposedly knowledgeable in areas. So whatever the reason for this absence, the Law stands as an empirical fact.

This Law should compel a certain kind of behavior on the part of leaders who see value in developing a shared point of view. The kind of behavior that is required is to create conditions whereby the linguistic domain of that group of individuals whose diversity of views creates unmanageable or ineffective organizational conditions is enlarged to the point where it becomes feasible to enunciate and share a point of view.

If the leadership is unable or unwilling to do this, at least the leadership should recognize the value in knowing that virtually all individuals in the pertinent group have quite diverse beliefs about any complex issue. The potential benefit that may be seen by a leader is the opportunity to

enter the policy or action vacuum and promote one's own point of view based on the held authority. The potential dysbenefit that might be seen by a leader is that the leader is usually no different from any other of the relevant individuals. The leader's views are just as likely to be unsatisfactory as those of any of the others.

LAWS OF COMPLEXITY: BRIEF 8B

NAME OF LAW: Limits

ORIGIN(S) OF LAW: Empirical

REFERENCES: None

STATEMENT OF LAW:

■ To any activity in the universe there exists a corresponding set of Limits upon that activity, which determines the feasible extent of the activity.

● The Corollary of Active Limits. The first Corollary to this Law asserts that for any particular situation, the set of Limits can be partitioned into two blocks: an active block and an inactive block. This Corollary is called the Corollary of Active Limits. The active block is the subset of the set of Limits that is determining at a given time, while the inactive block is not determining at that time. The active block may often consist of a single, dominating member of the set of Limits. Such a member may be so strong in its power to limit that, in effect, all other Limits are forced into hiding by the dominant one. When this occurs, it has both advantages and disadvantages. An advantage is that the designer who recognizes this situation can focus attention upon the dominant Limit and look for ways to modify its impact. A disadvantage is that the non-active Limits may go unrecognized, only to make their impact felt later upon the design activity that has focused overly on overcoming the dominant Limit.

● The Corollary of Movable Limits. The second Corollary to this Law asserts that the set of Limits also can be partitioned into these two blocks: movable and fixed. A movable limit is one that can be altered, while a fixed limit is one that is unchanging. Clearly if there is a dominant Limit and it is fixed, the potential exists for wasting substantial amounts of time, effort, and resources if one does not understand that it is fixed. On the other hand, if one mistakenly assumes that a Limit is fixed, when it really is movable, the potential exists for missing opportunities for major improvements. This Corollary is called the Corollary of Movable Limits.

- **The Corollary of Discretionary Action.** The third Corollary to this Law asserts that the movable subset of Limits can be partitioned into these two blocks: movable through discretionary action by people, and autonomously movable. Limits that are autonomously movable change on their own, and thereby drive the system. Clearly the strategic posture for dealing with such Limits is to maintain cognizance of their status and to have some predetermined alternatives in mind for coping with them when they move into prominence. This Corollary is called the Corollary of Discretionary Action. Limits that are movable through discretionary action by people are, of course, those that should be clearly recognized by designers, and to which attention should be given in the event that they are not overshadowed by more prominent Limits that effectively nullify the latent impact of those lying in the background.

- **The Corollary of Shifting Limits.** The fourth Corollary to this Law asserts that the membership of the active blocks and of the inactive blocks of the partitions changes with time. If, for example, discretionary action brings about a change in some moveable Limit that previously was dominant, one or more new Limits will take the place of the previously dominant Limit. This is the Corollary of Shifting Limits.

INTERPRETATION OF LAW:

The significance of this Law to the Science of Generic Design is that it conveys the importance of discovering (a) what the Limits may be upon design in general and how these Limits may relate to any particular Design Situation and (b) those additional Limits that are at work in a particular Design Situation. This Law and its Corollaries impose upon Theory the requirement that it contain explicit identification of generic Limits and explicit provision for the incorporation of special Limits.

The Law of Limits itself provides no means of identifying the Limits or of partitioning them after they have been identified. This capability must arise from other sources.

LAWS OF COMPLEXITY: BRIEF 8C

NAME OF LAW: Requisite Saliency

ORIGIN(S) OF LAW: Empirical

REFERENCES:

Kenneth Boulding (1966) The Impact of the Social Sciences, New Brunswick: Rutgers University Press.

J. N. Warfield (1994) **A Science of Generic Design: Managing Complexity Through Systems Design**, Second Edition, Ames, IA: Iowa State University Press (first edition, Salinas, CA: Intersystems, 1990).. See Appendix 5 for empirical data and the interpretation.

STATEMENT OF LAW:

■ The situational factors that require consideration in developing a design Target and introducing it in a Design Situation are seldom of equal saliency. Instead there is an underlying logic awaiting discovery in each Design Situation that will reveal the relative saliency of these factors.

INTERPRETATION OF LAW:

Kenneth Boulding identified three major reasons for poor intellectual productivity. These are: *spurious saliency* (emphasizing the wrong things, out of proportion to what they deserve); *unproductive emulation* (behaving like those who help create rather than resolve problems); and *cultural lag* (not using established knowledge with dispatch). Characteristically individuals who become involved in the design process *exhibit great diversity in their assessment of relative saliency* (as indicated in the data in Appendix 5 of **A Science of Generic Design**). This diversity, if uninfluenced by thorough exploration of the Design Situation, will support unfocused dialog, unjustified decisions, and arbitrary design outcomes not likely to be understood or even actionable.

The design process must incorporate specific provision for uncovering the relative saliency of the factors in the Design Situation and the factors that characterize the Target, in order to achieve the kind of understanding that is needed to put the design factors in proper perspective.

LAWS OF COMPLEXITY: BRIEF 8D

NAME OF LAW: Success and Failure

ORIGIN(S) OF LAW: Mathematics of discrete probability.

REFERENCES:

J. N. Warfield, J. N (1958) "Switching Circuits as Topological Models in the Discrete Probability Theory", Transactions of the IRE PGEC-7(3), September.

J. N. Warfield (1965) "Synthesis of Switching Circuits to Yield Prescribed Probability Relations", 1965 Conference Record on Switching Circuit Theory and Logical Design, Ann Arbor, MI, October, 303-309.

J. N. Warfield (1968) "Switching Networks as Models of Discrete Stochastic Processes", in Applied Automata Theory, J. Tou (Ed.), Chapter 4, New York: Academic Press, 81-123.

STATEMENT OF LAW:

■ There are seven critical factors in the SUCCESS BUNDLE for the Design Process. Inadequacy in any one of these factors may cause failure. The seven factors are: leadership, financial support, component availability, design environment, designer participation, documentation support, and design processes that converge to informed agreement.

INTERPRETATION OF LAW:

This Law indicates that a Science of Generic Design must define the critical factors in sufficient depth to enable (a) the assessment of their adequacy and (b) their application in the Design Situation. Success and failure must also be elaborated and, in this context, success in all stages of work, including the implementation and operation, is required in order to proclaim that the design is successful; while failure in any stage is sufficient to constitute failure of the design.

This Law furnishes the impetus for what is called the Sigma-N Concept discussed in detail in Sec. 6.9 of A Science of Generic Design).

LAWS OF COMPLEXITY: BRIEF 8E

NAME OF LAW: Uncorrelated Extremes

ORIGIN(S) OF LAW: Empirical, Statistical Analysis

REFERENCES:

I. B. Kapelouzos (1989) "The Impact of Structural Modeling on the Creation of New Perspectives in Problem-Solving Situations", Proceedings of the 1989 European Congress on Systems Science, Lausanne, Switzerland: AFCET, October, 915-932.

J. N. Warfield (1994) A Science of Generic Design: Managing Complexity Through Systems Design, Second Edition, Ames, IA: Iowa State University Press (first edition, Salinas, CA: Intersystems, 1990). See Appendix 5.

Warfield, J. N. (1995), "SPREADTHINK: Explaining Ineffective Groups", Systems Research 12(1) 5-14.

STATEMENT OF LAW:

■ No matter what the complex issue, and no matter what the group involved in its study, the initial aggregate group opinion concerning the logical pattern of the factors involved in the issue and the final aggregate group opinion concerning the logical pattern of the factors involved in the issue (i.e., the views at the two extremes of the application of the Generic Design Science, before and after), will be uncorrelated; showing that significant learning takes place through the application of the generic design processes.

INTERPRETATION OF LAW:

Once it was discovered that there was very great diversity in the views of individual members of groups about the relative importance of elements that were generated and clarified using the Nominal Group Technique (NGT), a research question arose about the persistence of such views after additional work was done. Since such elements were typically the subject of structuring work using Interpretive Structural Modeling (ISM), a natural way to approach this question involved a comparison of the results obtained from using ISM with the products of the voting done as part of the use of NGT.

While NGT is not regarded as a structuring tool, nevertheless a structure can be produced from the results of NGT voting. Here is how such a structure can be produced. For each problem element that gets at least one vote from a participant in group work using NGT, make numerical assignments to those votes as follows:

The highest rated element coming from some individual's voting gets a score of 5; the second highest rated element from that same individual's voting gets a score of 4; and so on, until the fifth-rated (lowest-rated) element gets a score of 1. Assigning such scores for every individual's votes, one can then compute a cumulative score for each element that received a vote. A structure can then be created using the relationship "has a higher score than", and this relationship can be regarded as equivalent to "is perceived by the group as a more important problem than".

Conducting the ISM session with the same elements, typically a problematique structure is produced using the relationship "aggravates". A method of scoring was developed whereby each problem element in the problematique receives a certain net score. This net score reflects the position of the problem element in the problematique, and takes into account the number of other problems that are aggravated by a given problem, as well as the number of problems that aggravate a given problem. Typically problems lying at the left will get larger scores than those lying at the right of the structure.

It then becomes possible to correlate the scores coming from the NGT-derived structure with the scores coming from the ISM-derived structure. While the two structures do not share precisely the same relation, one is justified in presuming that those problems that aggravate many other problems are more important than the ones they aggravate because of their power to sustain those other problems; while those that are, in effect, continued with increased power to do harm by others are regarded as less important. Importance thereby takes on a priority status, and reflects

the potential strategy of attack, working first on those that have the greatest power to aggravate other problems. Some data exist to show that this strategy has been very successful.

Judge I. B. Kapelouzos, who was on sabbatical leave from his position on the Council of State of Greece, decided that he would study 31 cases for which data were available to examine the before-and-after correlation for such structures. The "before" structure was the one produced from the NGT work, and reflects composite group results just before the ISM work begins. The "after" structure is the one that is available after the ISM work is finished.

People familiar with these concepts assumed that the work would show some variation from perfect correlation. Everyone was surprised to see the results. The results showed no correlation between the before-and-after structures. The startling nature of this result could only be explained in one way: the individuals in the group, after having gone through a rigorous examination of the relationships among the problems, learned a great deal about how those problems interact (something which they could not readily do otherwise, as indicated by the Law of Triadic Compatibility); and as a result the type of strategy indicated by their product changed dramatically as a result of this learning.

These research results imply, among other things, that all those methodologies currently in vogue for group work, which do not incorporate in their tool kit the ISM process whereby detailed examination of interactions among elements is carried out by the group, are sorely deficient and are likely to produce very misleading and dysfunctional conclusions.

Much more is learned from the process of detailed study of interactions among elements than intuition had suggested. Even though ISM was specifically designed to be a learning process, it was not envisaged that it would have the power which the Law of Uncorrelated Extremes attaches to it. Further research along these lines should be very valuable in adding to our limited knowledge concerning such matters.

Additional evidence to support the conclusions embodied in this Law are reflected in the Law of Structural Underconceptualization, where the data show unequivocally that individuals and groups do not even produce proper structures without the help of the ISM process, as discussed in the Interpretation of that Law!

LAWS OF COMPLEXITY: BRIEF 8F

NAME OF LAW: Induced Groupthink

ORIGIN(S) OF LAW: Empirical

REFERENCES:

I. L. Janis (1982), Groupthink--Psychological Studies of Policy Decisions and Fiascos, Boston: Mifflin.

G. T. Allison (1971), Essence of Decision, Boston: Little, Brown.

J. N. Warfield (1994) A Science of Generic Design: Managing Complexity Through Systems Design, Second Edition, Ames, IA: Iowa State University Press (first edition, Salinas, CA: Intersystems, 1990).

John N. Warfield and Carol Teigen (1993) Groupthink, Clanthink, Spreadthink, and Linkthink (1993), Fairfax: IASIS.

STATEMENT OF LAW:

■ The pathological behavior described as "Groupthink" (e.g., in the work of Irving Janis, and in Graham Allison's study of The Bay of Pigs incident), can be predictably induced in groups by the behavior of individuals who put pressure on groups to produce results under a time limit; where complexity is paramount.

INTERPRETATION OF LAW:

This Law, related to Groups, has its parallel in the Law of Forced Substitution, intended to explain certain behavior of a top-level executive.

The case study work done by Graham Allison, and the more elaborate and detailed case studies reported by Warfield and Teigen in the 1993 document titled "Groupthink, Clanthink, Spreadthink, and Linkthink", illustrates what this Law says.

LAWS OF COMPLEXITY: BRIEF 9

NAME OF LAW: Requisite Variety

ORIGIN(S) OF LAW: Mathematics, Systems Theory

REFERENCES:

Ross Ashby (1958) "Requisite Variety and its Implications for the Control of Complex Systems," Cybernetica 1(2), 1-17.

J. N. Warfield (1986) "Dimensionality", Proc. 1986 International Conference on Systems, Man, and Cybernetics, 2, New York: IEEE, 1118-1121.

J. N. Warfield and A. N. Christakis (1987) "Dimensionality", Systems Research 4(2), 127-137.

J. N. Warfield (1994) A Science of Generic Design: Managing Complexity Through Systems Design, Second Edition, Ames, IA: Iowa State University Press (first edition, Salinas, CA: Intersystems, 1990).

STATEMENT OF LAW:

■ A Design Situation embodies a requirement for Requisite Variety in the design specifications. Every Design Situation S implicitly represents an (initially unknown) integer dimensionality K_s , such that if the designer defines an integer K_m number of distinct specifications (whether qualitative or quantitative or a mix of these), then:

i) If $K_m < K_s$, the Target is underspecified and the behavior of the Target is outside the control of the designer

ii) If $K_m > K_s$, the Target is overspecified, and the behavior of the Target cannot be compatible with the designer's wishes

iii) If $K_m = K_s$, the design specification exhibits Requisite Variety, provided the designer has correctly identified and specified the dimensions; and the behavior of the design should be that which the Situation can absorb and which the designer can control, subject to the requirement that the dimensionality of the Situation is not modified by the introduction of the Target into the Situation.

If the dimensionality is changed thereby, the design process can apply the Law of Requisite Variety iteratively, taking into account the dynamics of the Situation.

INTERPRETATION OF LAW:

The Theory of Dimensionality has been introduced, in part, to make possible this formulation of the Law of Requisite Variety, especially to enhance applicability of it to those situations where some dimensions are naturally quantitative and some are naturally qualitative, requiring that both kinds of dimensions be in a common space and subject to comprehensive interpretation in order to achieve a sound design result.

The question might be raised as to how designers have succeeded in the past in the absence of overt response to this Law. Many, if not most, Targets of design are redesigns that benefit from decades of experience which have permitted the development of intuitive knowledge that

substitutes for overt application of this Law. Regrettably, it is this same cumulative experience that mistakenly leads designers and their managers to believe that somehow they can intuitively design systems much larger in scale that have never been designed before.

LAWS OF COMPLEXITY: BRIEF 10A

NAME OF LAW: Forced Substitution

ORIGIN(S) OF LAW: Empirical

REFERENCES: None

STATEMENT OF LAW:

■ **Structural underconceptualization and inherent conflict lead to policy vacuums in an organization into which authority injects forced substitution for absent and inadequate conceptualization, in order to avoid institutional paralysis and for self-protection.**

INTERPRETATION OF LAW:

This Law reflects the empirical knowledge that executives in charge of large organizations are essentially forced to take action in regard to problems of the organization. The very large pressures on such executives will be relieved in the short run by taking action. A question of much importance has to do with how effective such action will be.

It has been pointed out by Peter Senge that while executives often have significant amounts of experience on short-term issues of relatively little complexity, such executives often have no reliable experience regarding longer-term issues which are complex. A simple explanation is that by the time the consequences of the decisions they make are felt, those executives have changed positions, and are not even around to experience directly those consequences. Another explanation has to do with the fact that complex issues are quite small in number compared to the many normal issues facing organizational leadership, so even the statistics work against gaining relevant experience. It is unreasonable to expect that the executive who is making decisions about complex issues is any better equipped to make such decisions than anyone else inside or outside the organization.

The combination of being required to make a decision about a complex issue and the lack of high-quality analysis and experience related to that issue is perfectly calculated to produce action that will not be effective and may make matters worse.

Because it is possible to apply methodology that is compatible with and recognizes the

importance of the Laws of Complexity, it is reasonable to postulate that such an analysis or design could have been produced if the leadership were both aware of and willing to sponsor such activity. The choice of the term "Forced Substitution" recognizes that the decision-maker is substituting a "hip-pocket" or "wet-thumb" decision for what could have been a highly-informed decision, informed, among other things, by the structure of the issue; and that the decision-maker is forced by circumstances to make such a decision because to do otherwise would convey an image of ignorance and indecision which (even though it might well be warranted) is not what boards of directors are willing to tolerate.

They will accept bad decisions (unwittingly or otherwise), unsupported by the kind of analysis and design that is now possible to attain taking into account knowledge of the Laws of Complexity, but they will not support inaction.

LAWS OF COMPLEXITY: BRIEF 10B

NAME OF LAW: Precluded Resolution

ORIGIN(S) OF LAW: Empirical

REFERENCES: None

STATEMENT OF LAW:

■ **Forced substitution in organizations is dominated by the combination of:**

- **structural underconceptualization**
- **inherent conflict and diversity of belief**
- **dysfunctional organizational linguistics**

which combine to preclude resolution of complex issues.

INTERPRETATION OF LAW:

This Law is intended to explain the reasons why complex issues are seldom resolved in organizations. The explanation is given in terms of what several other Laws of Complexity have to say.

Recognizing that there is much diversity of belief, and much inherent conflict in the views of individuals concerning the relative importance of various elements germane to a complex

situation, at the beginning the organization is in intellectual disarray about the complex issue.

If the organization does not have any effective methodology for learning about the issue, and if it does not use the process of Interpretive Structural Modeling to develop the structural patterns that explain the issue (and very few organizations presently do this), whatever individual's particular uninformed perceptions become the basis for action will necessarily exhibit structural underconceptualization, and will then promulgate an uninformed approach to an implementation scheme already lacking support in the organization.

In the absence of any well-designed means for developing the necessary organizational linguistic domains, people will not even be able to share a mutual understanding of what was wanted and therefore cannot be effective or even mutually reinforcing in implementing bad decisions emanating from a perceived requirement to take some action.

In other words, there is an overwhelming set of institutional conditions that virtually guarantee that complex issues will not be resolved, and the analysis that explains the reason for the persistence cannot help but be supported by the anecdotal evidence being seen in everyday life as to the ineffectiveness and dysfunctionality of systems put in place with improper designs that are unresponsive to the situations they were purported to remedy.

LAWS OF COMPLEXITY: BRIEF 11

NAME OF LAW: Triadic Necessity and Sufficiency

ORIGIN(S) OF LAW: Mathematical Logic

REFERENCES:

J. Brent (1993) Charles Sanders Peirce: A Life, Bloomington, IN: Indiana U. Press.

R. W. Burch (1991) A Peircean Reduction Thesis, Lubbock, TX, Texas Tech U. Press.

STATEMENT OF LAW:

■ Relations are characterized by the number of distinct relational components, but no matter how many such components a relation may have, the (complex) relation can always be expressed by component relations having no more than three relational components; but triadic relations exist that cannot be expressed in terms solely of dyadic and monadic relations.

INTERPRETATION OF LAW:

Charles Sanders Peirce studied the logic of relations extensively. In the recent (1993) biography of Peirce by Joseph Brent, the following passage appears:

"Abstract forms of relation are objects of a mathematical inquiry called the logic of relations (or relatives), which Peirce began to examine in 1870 with his 'Description of a Notation for the Logic of Relatives'. By 1885 he had proposed in what Hans Herzberger [Professor of Philosophy, University of Toronto] has called 'Peirce's remarkable theorem,' that there are only three fundamental kinds of relations: monadic, dyadic, and triadic; that by combining triads, all relations of a greater number than three can be generated; and that all those of a greater number than three can be reduced to triads. Since, in addition, triads cannot be reduced to dyads, nor dyads to monads; monads, dyads, and triads constitute the fundamental categories of relations. At the same time, triads are made up of dyads and monads, and dyads of monads."

According to Robert W. Burch [Professor of Philosophy at Texas A & M University], others who have examined related issues include Quine, Löwenheim, Schröder, Herzberger, and Ketner. The following passage appears in Burch's 1991 book referenced above:

"By extending both the algebraic ideas of Herzberger and the graph-theoretical ideas of Ketner, this work proposes to develop an algebraic formalism in which a reduction thesis similar to and perhaps identical to the reduction thesis Peirce had in mind can be proved for the general case. This work also proposes to show that the reduction thesis it proves is consistent with the work of Löwenheim and the result of Quine, despite that the fact that these results may appear to conflict with it."

The proof developed by Burch is long and thorny, but it has been examined by other mathematicians who have not detected any flaw.

If we accept the proof at face value, then we are impelled to note the interesting comparison of this Law with the Law of Triadic Compatibility. Putting the two together we arrive at the result that the number 3 not only is the maximum number of elements whose interactions can reasonably be dealt with in short-term memory because of the limits of recall, but also it coincides with the maximum number of elements that must be dealt with modularly in order to be able to deal with complex relationships of any magnitude.

The full significance of the foregoing is unclear at the present time, because of the limited amount of investigation into the consequences of accepting all of the foregoing as established scientific fact. But the potential significance is so great, and the absence of any evinced alternative other than to continue the present disjointed incrementalism ("muddling through") advocated by Braybrooke and Lindblom and so commonly practiced in organizations, provides strong motivation to those who are severely concerned with the defects in present organizational practice to move ahead on the basis of the hypothesis that what is said in the foregoing paragraph is both true and the appropriate guidance for changing organizational practice and culture.

LAWS OF COMPLEXITY: BRIEF 12

NAME OF LAW: Small Displays

ORIGIN(S) OF LAW: Empirical

REFERENCES:

James Martin and Carma McClure, Diagramming Techniques for Analysts and Programmers (1985), Englewood Cliffs: Prentice-Hall.

Any User Guide to computer graphics software.

STATEMENT OF LAW:

■ **Individuals, faced with a responsibility to help illuminate complexity, will typically fail to distinguish complexity from normality in their choice of media for displaying their work, and will continue to accommodate their behavior to the constraints imposed by small display media (e.g., 8 1/2 x 11 inch or A4 paper size, and/or small computer screens and standard-sized transparencies), instead of insisting on matching the size of display space to the complexity of the subject matter.**

INTERPRETATION OF LAW:

If one imagines a scale related to complexity of issues, ranging from the very simplest imaginable to the most difficult imaginable, one can then consider how the scale of representation enlarges as the scale of the issue enlarges. Notably a point is reached where as the complexity grows, the scale of representation stops changing at the point where conventional media have established benchmark dimensions.

Even the university has established a standard size of chalk board, as though no matter what is being taught can be represented within that scale. This assumption goes hand in hand with another; which is that linear, sequential presentations are the only kind that will ever be used in representing subject matter. The fact that the latter belief is readily contradictable seems irrelevant to university administrations. Why choose the university as a focal organization? Because it is this institution that blesses the practice by carrying it out repeatedly, day after day, to all of its clientele; thereby setting a standard for society to follow. It is, therefore, the same institution that could change the practice, simply by acknowledging it and creating an infrastructure to deny its universality.

NAME OF LAW: *Complexity*

CHARACTER OF LAW: *Complexity*

ORIGIN OF LAW: *Complexity*

REFERENCE: *Complexity*

STATEMENT OF LAW: *Complexity*

ANY DATA USED TO SUPPORT STATEMENT: *Complexity*

STATEMENT OF LAW: *Complexity*

REFERENCE: *Complexity*

STATEMENT OF LAW: *Complexity*

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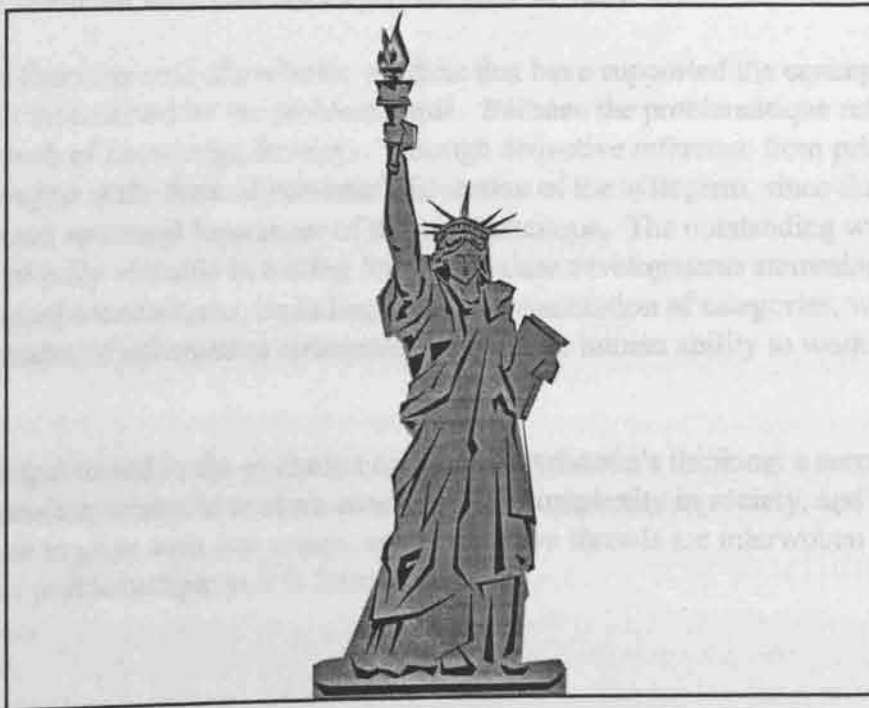
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STATEMENT OF LAW: *Complexity*

REFERENCE: *Complexity*

THE PROBLEMATIQUE: EVOLUTION OF AN IDEA

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"sum, ergo cogito"

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THE PROBLEMATIC EVOLUTION OF A IDEA

John A. W. G. G.
George H. H. H. H.
at 100
George H. H. H. H.



"The Statue of Liberty"
George H. H. H. H.

ABSTRACT

In its present conception, a problematique is a structural graphic whose graphics linkages reveal how a collection of problems interrelate to form an overall pattern of significant aggravation. Such a graphic has been found to provide many benefits in unraveling complexity, including insights into priorities in striving to resolve complexity. While the problematique is just one of several key graphics types that have been found to be beneficial in studying problematic situations, it is arguably the most frequently-developed type. It is estimated that hundreds of problematiques have been produced by groups, assisted by software founded in what is called here "the mathematics of multitudes".

Issues related to resolving complexity have been considered, in one way or another, for a long time. Since the problematique is a recent development in that long train of investigation, it seems appropriate to consider this question:

What prior developments occurred, without which it seems reasonable to suppose that the problematique could not have reached its present state at this time?

There is a long literature trail of evolution of ideas that have supported the conceptualization and implementation represented by the problematique. Because the problematique reflects the cumulative growth of knowledge developed through deductive inference from prior knowledge, the evolution begins at the time of Aristotle's invention of the syllogism, since that invention is the earliest known structural forerunner of the problematique. The outstanding work of Bochenski is uniquely valuable in tracing forward in time developments stemming from Aristotle's original contributions, including his conceptualization of categories, which today enable development of information structures that enhance human ability to work with complexity.

While the principal thread in the evolution connects to Aristotle's thinking, a second major source of information relates to modern concerns with complexity in society, and with how people can come to grips with that complexity. These two threads are interwoven to show the evolution of the problematique as it is found today.

THE PROBLEMATIQUE: EVOLUTION OF AN IDEA

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1.0 INTRODUCTION.

Undeniably, the world has become steadily more complex. Organizations find themselves facing a requirement to work with a variety of *problematic situations*. Typically these situations involve large numbers of interacting problems. How should organizations proceed to improve their capacity to work with these situations?

Today there exists a concept called "the problematique". A problematique is a member of a class of graphical constructs, aimed at portraying a pattern of interaction. It is a very sophisticated idea whose time has come. In the past two decades hundreds of problematiques have been constructed, revealing patterns of great significance to the organizations for whom such patterns have meaning. Other members of the same class have also been applied, but learning about the problematique will illuminate many features of all members of the class.

The problematique has evolved over time from a primitive existence, to an essentially metaphorical existence, to a scientifically-based entity yielding a large variety of benefits relevant to understanding and managing complexity.

This essay traces that evolution through time, showing events, scattered in time, that have come together in this one versatile and ubiquitous graphical device for enhancing human understanding, and facilitating the development of action plans for correcting undesirable situations.

The story of this evolution includes fundamental developments: e. g., the invention of the mathematics which form much of the scientific foundation for the construction and interpretation of problematiques. The development of the mathematics then flows into the establishment of an analytical connection between an integrated collection of mathematical developments and appropriate graphical portrayals. Once it is understood that the mathematics correlate with (i.e., are symbolically, though not behaviorally, isomorphic with) graphical portrayals, the evolution can be seen to require the development of a process whereby such portrayals can be synthesized. The process was developed.

After the process is developed, a significant period of time must evolve in which that process is tested, and the means of interpreting the product are analyzed. The benefits obtained by

constructing a problematique need to be identified and clarified, and that occupies a significant portion of the period of evolution. While the problematique initially is developed through a qualitative process, ultimately it becomes feasible to attach numerical values to various aspects of the problematique. These values, in turn, have specific merit in interpreting the problematique and in assessing its complexity.

The role of the problematique in the philosophy of science ultimately is clarified through references to the philosophy of Charles Sanders Peirce.

The added utility of the "Problem Field", when it is developed as an adjunct to the problematique, becomes a part of the evolutionary understanding. The value of the problematique and the problem field taken together is strong in enhancing the quality and utility of vertical communication within large organizations, enabling a coherence between high-level strategies and lower-level-change requirements to be designed, maintained, and implemented.

2.0 THE SYLLOGISM

- (1) "...An argument or form of reasoning in which two statements or premises are made and a logical conclusion is drawn from them.
- (2) Reasoning from the general to the particular; deductive logic."

--*Webster's New World Dictionary (1993), Third College Edition, Prentice-Hall, page 1356.*

Aristotle (384-322 BC) is regarded as the earliest major logician.

"For Aristotle, logic was preparation for scientific knowledge, not knowledge itself. He was the first to insist on rigorous scientific procedure, and his method of demonstration by the syllogism and by dialectic, or reasoning from the opinions of others, became standard philosophic method."

--*Benét's Reader's Encyclopedia (3rd Ed., 1987) New York: Harper & Row.*

A commonly cited syllogism, slightly modified, reads as follows:

Socrates is a man.

Each man is mortal.

Therefore Socrates is mortal.

The highlighted word "is" in this syllogism is referred to as its "copula".

Over 2,000 years following the death of Socrates, Augustus De Morgan (1806-1871) would introduce a notation for relationships, e.g., for the copula in the example syllogism. By

symbolizing the elements that the copula joins, one could replace the syllogism above by a generic form: ARB, BRC, therefore ARC. In this instance, A represents "Socrates", B represents "man", and C represents "mortal". About 1,400 years after the death of Socrates, but before De Morgan conceived the generic form just cited, Pierre Abélard (1079-1142) would write the prose equivalent of De Morgan's generic form, quoted in the very scholarly work by I. M. Bochenski (1902-) titled *A History of Formal Logic*. In this work, Bochenski (a member of the Dominican order) traced the developments in logic from about 500 BC up to about 1930 AD. He offers numerous quotations from original sources, providing a perspective on the evolution of formal logic that is not apparent from any other author.

3.0 NOTABLE DEVELOPMENTS IN MATHEMATICS

In all of the period extending from Aristotle's time until the 1700's, the syllogism was an object of continuing study. Great attention was given to many forms of the syllogism, but all of them involved three basic statements.

According to Bochenski, the work of Gottfried Leibniz (1646-1716) signals a turning point in the development of formal logic. Leibniz recognized that many assumptions were being made about language, in effect taking it as a given, while the validity of the syllogism clearly depends upon understanding in detail what each term from the natural language entails. Moreover, Leibniz recognized that the development of science was severely constrained by the acceptance of the natural language as the language of science. He promoted the idea that any science requires a designed language, carefully constructed to allow for more precise expression than the natural language could provide, in order that the relevant scientists can communicate their ideas in ways that allow them to be understood by and tested by other scientists.

Later, David Hilbert (1862-1943) would formalize the linguistic distinctions with his concepts of formalism, metalanguage and object language.

The elementary concepts of graphical denotation, of which the well-known "Venn diagrams" are an example, appear in Leibniz's research notebook. While Venn was a nineteenth century scholar, researchers now know that the Venn Diagrams were previously used by Leonhard Euler (1707-1783), being called "Euler's Circles" and, as Bochenski shows in a photograph from Leibniz's notebook, Leibniz was using such diagrams in advance of Euler (see page facing 261).

The syllogism and the Venn-Euler-Leibniz diagrams share a common weakness. They are limited to a small number of components; the syllogism being limited to three, and the diagrams being limited to a modest number capable of being distinguished from one another on a particular page where they typically overlap one another. It was becoming clearer (after more than 2,000 years) that there was a great need for what might be called "the mathematics of multitudes"; i.e., a language which facilitated a notation and operations that can encompass many, many components.

It is notable that what might be called "the mathematics of multitudes" was developed strongly during the eighteenth and nineteenth centuries. Some of the key developments were:

- Graph Theory (Leonhard Euler, 1707-1783, and others later)
- The Theory of Relations (Augustus De Morgan, 1806-1871)
- An Algebra of Logic (George Boole, 1815-1864)
- A theory of matrices (Arthur Cayley, 1821-1895)
- A theory of sets (Georg Cantor, 1845-1918)

A unique book appeared in the twentieth century in which these branches of mathematics were united in an integrated way to clarify the concept "structural model". The leader in this effort was Frank Harary (1921-). In a jointly-authored work²⁴ the authors demonstrated a strong connection between mathematical models and these branches of mathematics. Among other things, they showed clearly that behind every "numerant" mathematical model there lies an often-suppressed "structural model" that is representable by a digraph model. Moreover the latter is representable in algebraic form through the connections between set theory and the theory of relations.

This book is one of a very small number of mathematical works in which the products of two or more distinct fields of mathematical study are integrated to show how their combined strengths can make possible applications theretofore only dimly perceived.

4.0 PEIRCE AND THE PHILOSOPHY OF SCIENCE

The American scientist-logician-philosopher Charles Sanders Peirce (1839-1914) was urged by his famous father, Benjamin Peirce (1809-1880), to study the great philosophers and determine where they were mistaken. In a life devoted to science and to developments in logic, Charles took on that challenge, and made major contributions to formal logic, as well as to the philosophy of science, and other areas. (The name "Peirce" is pronounced "purse".)

Charles studied intensely the theory of relations of De Morgan. Both of them shed light on the nature of the syllogism and the conditions under which the inference component of the syllogism would be correct.

As Bochenski indicates (page 320), De Morgan was well aware of the significance of *transitivity of the copula* as a condition for validity of a syllogism. Peirce, in his 1892 article "The Critic of Arguments", shed more light on the situation.

²⁴ F. Harary, R. V. Norman, and D. Cartwright (1965), *Structural Models: An Introduction to the Theory of Directed Graphs*, New York, Wiley.

"Peirce demolishes the doctrine that syllogism presupposes the laws of thought as a condition of its validity. He shows that the one mood of universal affirmative syllogism, *Barbara*, depends not upon the principle of identity, but upon the fact that the relation expressed by the copula is *transitive*."

-- T. A. Goudge (1950), *The Thought of C. S. Peirce* (page 124), Toronto: The University of Toronto Press.

5.0 BOCHENSKI'S HISTORY OF FORMAL LOGIC

Bochenski's work has already been mentioned above. It deserves a special section in this document because it is the key work in learning the history of formal logic. One importance of this work is the insight it can give us in these areas:

- **The Slow Pace of Science (as opposed to technology).** It tells us how slow humanity's progress has been in gaining the wisdom required to comprehend formal logic; e.g., over 2,000 years of study of the 3-statement syllogism did not reveal the significance of transitivity of the copula, which came only through the insights of De Morgan and Peirce. The significance of this knowledge is best understood when one sees how the "mathematics of multitudes" alluded to in the foregoing is critical in the construction of models that link many elements.
- **Rediscovery in Science.** It tells us how much rediscovery goes on as, for whatever reason (e.g., lack of access to older publications, desire to originate rather than to discover from the past) Bochenski is able to mention in many places evidence of the failure to assign correctly the origination of key ideas, and evidence of the rediscovery of ideas developed centuries in the past.
- **A Standard of Comparison.** By its mere existence, it illustrates the shallowness and superficiality of much of today's literature, through comparison with this in-depth and responsible work, that gives much attention both to identifying and to quoting original sources. Perhaps it also suggests that university faculty members who insist on teaching classes to Ph. D. students instead of concentrating on research and upgrading of knowledge may be likely to propagate erroneous knowledge indefinitely.

6.0 HARARY AND THE ANALYTICAL INTEGRATION

Previously the work of Harary in carrying out an analytical integration of various components of what is called here "the mathematics of multitudes" has been highlighted. This work is fundamental to the eventual development of the most recent form of the problematique.

7.0 OZBEKHAN, CHRISTAKIS, AND THE CLUB OF ROME

The origins of the Club of Rome will now be discussed, along with what appears to be an original and novel use of the term "problématique", which is a key part of its evolving connotation discussed in this paper. This usage incorporates the clear intent to promote a substantial increase in the quality of models that are developed to help people interpret what is going on in the world that is of broad importance; events that may require significant design and implementation of change.

A prospectus titled *The Predicament of Mankind* was prepared in 1970 for submission to the Club of Rome. The developers were Hasan Ozbekhan and Alexander Christakis. This 77-page document presented a conceptual framework and work procedures, a brief history of the Club of Rome, concepts for further development of the Club, and a Work Statement and Proposal²⁵.

The Club of Rome was started following a meeting convened in Rome in April, 1968, by the Giovanni Agnelli Foundation and the National Academy of Lincei to discuss new approaches to the problems of world society. At the end of this meeting a number of those present, increasingly concerned about the symptoms of breakdown of our society that are appearing simultaneously with higher levels of prosperity and the ever-quickenening application of new technology, decided to continue to work together, and called their group "The Club of Rome" after the city of its origin. The Club was incorporated in March, 1970, in Geneva, as a non-profit private association under the Swiss Civil Code, the Secretariat to be in Rome.

Three objectives were formulated, in the early stages, the essence of which are as follows:

- "To contribute toward an understanding of the problems of modern society considered as an ensemble ... concentrating particularly on those aspects that concern all or large sections of mankind."
- "To heighten the awareness that this complex of tangled, changing, and difficult problems constitutes; over and above all political, racial or economic frontiers; an unprecedented threat to all peoples..."
- "To make the results of the[se] studies and reflections known to public opinion...in order to influence to the utmost extent the conduct of the world's affairs in a more rational and human way."

In reviewing the background for the "situation" confronted in the world, Professor Hasan Ozbekhan, assisted by Dr. Alexander Christakis, introduced the concept of "problématique"²⁶:

"It is in the nature of our languages, hence of our manner of perceiving reality, to see and call the dissonant elements in a situation, 'problems'.

"Similarly, we proceed from the belief that problems have 'solutions' -- although we may not necessarily discover these in the case of every problem we encounter. This peculiarity of our perception causes us to view difficulties as things that are clearly defined and discrete in themselves. It also leads us to believe that to solve a problem it is sufficient to observe and manipulate it in its own terms by applying an external problem-solving technique to it.

"...It is also becoming quite evident that such problems are no longer the most important ones with which we must deal...for even the most cursory examination will reveal the more obvious (though not necessarily the most important) links between problems. Where endemic ill-health exists, poverty cannot easily be divorced from it, or vice versa. Certain kinds of criminal behavior often, though not always, seem to be related to poverty or slum living conditions. Furthermore, if we try to solve any such problems exclusively in their own terms we quickly discover

²⁵ A copy of the prospectus, titled *The Predicament of Mankind* was loaned to by Alexander Christakis. Information has been drawn freely from that seminal document, in writing the paper that you are reading now.

²⁶ Professor Ozbekhan, rightly, used the French term, as just written. For general purposes, I conclude that this term is now sufficiently established in English to be written without the accent symbol over the e, and I have followed that practice, except where I refer specifically to Ozbekhan's work.

that what we take to be the solution of one kind of problem may itself generate problems of another kind (the reduction of death rates in developing areas and the resultant increase in poverty, public unrest, overpopulation, etc., is a good example of this single avenue approach).

"...It seems reasonable, therefore, to postulate that the fragmentation of reality into closed and well-bounded problems creates a new problem whose solution is clearly beyond the scope of the concepts we customarily employ. It is this generalized meta-problem (or meta-system of problems) which we have called and shall continue to call the 'problématique' that inheres in our situation.

"If we are to learn something new it would appear, therefore, that we need to create one or more situational models which might reveal -- with reference to, but almost independently from, the problem clusters:

1. the identity of the most critical and sensitive components of the situation;
2. the main or major interactions that exist among the various variables contained in the situation;
3. the behavior of the main variables in relation to changes within the situation;
4. the time-dependent ordering of the chief possible outcomes and of their present consequences for action;
5. the presently invisible critical connections that operate systematically within the present situation and that situation's future configuration;
6. the positive and negative synergies that must exist among various alternative consequences and options."

In introducing the problématique graphically (pages 20 and 21 of the Prospectus), the authors used a sequence of drawings akin to what are popularly known as "Venn diagrams", beginning with a drawing where each problem area is represented by a geometrical figure separate and removed from each other problem area. In the next drawing in the sequence, growth and movement of these areas is indicated, but the areas are still distinct, though moving toward one another. In the third drawing, the areas have grown further and now overlap significantly. The idea of the problématique appears as the consequence of a steadily growing collection of problem areas which, over time, begin to run together and create, ultimately, a heavily interconnected group of problem areas. With respect to these areas, there appear "clusterings and overlaps, **which we may perceive superficially but whose real structure and dynamics escape us.**"

8.0 ACKOFF'S CONCEPT: A "MESS"

When Russell Ackoff took the lead in the early 1970's to initiate a new doctoral program in "Social Systems Science" in the Wharton School of the University of Pennsylvania, he enjoyed an association with Hasan Ozbekhan as a principal colleague. Among the ideas emphasized by Ackoff was what he called (and continues to call) "a mess" or "a system of problems". Because of the widespread dissemination of this terminology, one can say that Ackoff helped raise consciousness among academic areas of the importance of working with collections of interacting problems. On the other hand, this step in the evolution apparently did not recognize or move into the potential application of what are called here "the mathematics of multitudes". Instead, it appears that Ackoff strongly emphasized group activity to take into account these messes in arriving at organizational plans.

9.0 BATTELLE, DEMATEL AND THE CLUB OF ROME

As the Prospectus for the Club of Rome indicates, one of the key early members was the Battelle Institut of Geneva, Switzerland; Battelle-Geneva. This organization was established by the American parent, the Battelle Memorial Institute of Columbus, Ohio, which was originally chartered under the benevolent gift of funds from Gordon Battelle, a leader in the early steel industry in Ohio, and the last of his line. At the end of World War II, Battelle was asked to help in the recovery of Europe by establishing research institutes in Europe to provide contract services to industry and government. Battelle responded by establishing such institutes in Frankfurt, Germany, and Geneva, Switzerland. These new institutes enjoyed considerable autonomy, within restrictions imposed by the laws of the various involved nations.

After the Club of Rome had begun to act, Battelle took upon itself the internal sponsorship of research aimed at helping to attain the three objectives mentioned above. Specifically, with leadership from Dr. Bertram Thomas, Dr. Russell W. Dayton, Dr. Ron Paul, Dr. Sherwood Fawcett, and Mr. Roger Merrill, among others, Battelle established an internal research program titled "Science and Human Affairs".

The Geneva component of this program used the acronym "DEMATEL" to represent its major thrust. This acronym could represent "Decision-Making and Testing (or Trial) Laboratory". One of the major projects carried out there involved the identification of approximately 50 "world problems", i.e., problems that an individual nation could not resolve, but which required cooperation among (some or many) nations of the world. As mentioned in the foregoing, it was recognized that there would be many interactions among these problems; so it was felt that it would be important to comprehend the nature of these interactions.

To help clarify this, Battelle-Geneva developed a large questionnaire which they hoped to give to world leaders who would then provide their views of the nature and intensity of such interactions. It was hoped that "schools of thought" or perhaps just one widespread school of thought could thereby be discovered.

When about 20 world leaders returned their questionnaires, Battelle discovered that there were essentially as many schools of thought as there were leaders. There was no discernable actionable pattern that could form the basis for a consensual program.

(About two decades later, Warfield discovered a phenomenon called "Spreadthink" discussed later in Section 24, by observing data from many Interactive Management Workshops. At the time of the DEMATEL program, it was supposed that this diversity of opinion was unique to the set of world problems. But now, in retrospect, if Spreadthink had been understood, there would not have been an expectation of finding one or a small number of schools of thought. Instead, again in retrospect, the conclusion would be that a process was required which would involve the world leaders, and which would enable them to develop collectively a school of thought reflecting their aggregated, structured best thinking.)

At the same time, the Battelle Columbus Laboratories initiated a program under the Science and Human Affairs banner titled "Science Base". This program was assigned to John N. Warfield, who had proposed to explore the scientific depths related to the description, diagnosis, and understanding of complexity, as involved in interrelated problem sets; with the ultimate aim of developing new processes that would enable design or redesign of large-scale systems to help resolve the world problematique (or situations of lesser scale, but still complex due to interactions). The proposal, in a pamphlet with a gold cover, came to be known colloquially as "The Gold Book"²⁷. One of the principal products of that activity will be discussed next.

10.0 INTERPRETIVE STRUCTURAL MODELING (ISM)

In 1974, Battelle published Monograph Number 4, titled, *Structuring Complex Systems*. This monograph set forth the theory of what was named Interpretive Structural Modeling (ISM). This work drew heavily from, but had to build significantly on, the book by Harary, et al. The Harary work established the analytical basis. However it did not include a process whereby the kinds of structural models illustrated in the work could be systematically developed by human beings working as a group, based on substantive understanding of the difficulties involved in dysfunctional large systems.

Basic questions dealt with in the Science Base project were:

- How can people develop structural models showing the details of how a large set of elements interrelate?
- How can people portray structural models in a way that enables them to be interpreted?

Partial results of this work appeared in Battelle Monograph Number 4, as mentioned, but a more complete description appeared two years later in this reference:

John N. Warfield (1976), *Societal Systems: Planning, Policy, and Complexity*, New York: Wiley Interscience.

ISM depends heavily upon the mathematics of multitudes. Warfield found it necessary to restate several branches of this subject in the *Societal Systems* book, because the way these branches were integrated in developing ISM involves the need to use a common notation across these branches. Again, the Harary work provided much of the foundational thinking, but had to be augmented considerably; and the notation had to be amended to reflect an orientation toward synthesis, which is essential for the purposes of model development.

ISM also draws heavily upon the transitivity condition mentioned in the preceding: a condition

²⁷ R. W. Dayton, E. R. Irish, and J. N. Warfield (November 23, 1971), "Proposed Study of Developing Improved Methods for Dealing with Complex Societal Problems", Columbus, OH: Battelle Memorial Institute, 38 pp. plus appendices.

developed through the thought of Abélard, De Morgan, and Peirce; and put into Boolean matrix form by Harary, et al.

A key discovery in developing ISM involved the manner of denoting and constructing a square matrix, to be filled with 1's and 0's, to be operated on repeatedly through Boolean logic (as augmented by Warfield), as it is being constructed. In developing the matrix it was found possible to take maximum advantage of deductive inference, involving the concept of transitivity, using the computer to manage the application of logic principles. To explain this, additional discussion of transitivity will be given. **This discussion also is intended to suggest why ISM is useful in developing many types of structures other than the problematique.**

11.0 TRANSITIVE INFERENCE

Transitivity of the copula has been emphasized in the foregoing. This condition makes possible repeated application of transitive inference in developing patterns of complexity.

As ISM was developed, it embodied the following key ideas:

- Large-size structural models are of interest only when there is some kind of "flow" in the relationship among the components of the models
- Flow in the relationship is a natural consequence of the transitivity of the relationships among the components of the models
- The strength of ISM lies in the way in which its computer implementation facilitates the use of transitivity to develop and portray that flow. (Some have suggested that it is a shortcoming of ISM that it does not accommodate non-transitive relationships. But they have not proceeded to identify any rationale for dealing with such relationships, which generally do not involve any flow.)
- The development and interpretation of a structural model is greatly facilitated if the model is built upon a "simple" rather than a "compound" relationship. This enables transitivity to be established, and its advantages to be used in developing the models
- Should it become desirable to formulate models involving compound relationships (e.g., "taller than **and** heavier than"; or "aggravates **and** is included in", they can be formulated by constructing the set union of the component relationships
- Substantial savings in time accrue from use of the transitivity condition to allow machine inference from partial information. This use also provides efficiency benefits in determining the sequence of model-development operations, exploiting transitivity
- To facilitate choice of a relationship to use for modeling, relationships should be categorized, to make clear the menu of choices for developing structural models
- Particular structural types should be discovered and clarified, to take advantage of the learning that accrues by working with standard types, where appropriate (the problematique is one of a number of standard types, as is the problem field, to be discussed later)
- The computer should control the model sequencing, by presenting questions visually to the people who are developing the model, and should compute the model structure so that it can be laid out and displayed (frequently in a large wall display)

12.0 DOXIADIS AND THE SLIDING PANELS

During a visit by Warfield and Christakis to the architectural offices of the Doxiadis architectural firm in Athens, Doxiadis demonstrated the use of large sliding panels to present graphically the many options available to urban planners. These options were arranged in categories, and were very effective in saving the time of urban planners who were contemplating a major planning effort for large urban areas. These panels were arranged side by side on tracks with wheels, so that a particular panel could be rolled out, discussed in depth, and then rolled back.

These panels reinforced the idea that large displays are essential in providing overviews of situations involving numerous problems. For that reason, it seemed clear that small printouts or small-screen displays could never be adequate to give comprehensive overviews for discussion and learning. This idea came to fruition later, when a special-purpose facility was designed to use in the process of model development.

13.0 AN EARLY PROBLEMATIQUE

One of the first problematiques ever developed was applied in an industrial setting. The John Deere Company, in Waterloo, Iowa, was having problems with a manufacturing line for an expensive pump. At that time, Dr. Robert J. Waller, who was Dean of the School of Business at the University of Northern Iowa in Cedar Falls (a city next door to Waterloo), proposed the use of ISM to engineers at Deere, with the aim of trying to unravel the complexity associated with the pump manufacture. Figure 1 illustrates the structure of this problematique, from which the problem statements have been excised. The problem statements are represented in Figure 1 by the numbers inside the boxes. Some of the numbers are shaded. The shaded problems make up a set of 5 that were collectively studied, and their study produced a very satisfactory outcome, resolving the difficulties causing problems earlier.

The description of this situation is available in greater detail than presented here²⁸. (The problem statements are given in the reference and are shown in full in the associated drawing.) This application is of historical interest because it demonstrated a clearly successful application of the problematique to a concrete industrial issue, and encouraged the continued development and use of the problematique in a much broader set of situations.

14.0 LATER PROBLEMATIQUES

Since the early applications of the problematique, occurring in the late 1970's and early 1980's,

²⁸ John N. Warfield (1994), *A Science of Generic Design: Managing Complexity Through Systems Design*, Second Edition, Ames, IA: The Iowa State University Press, p 395.

many problematiques have been produced by groups, and applied successfully to the interpretation of situations previously thought to be intractable.

An especially notable example of repeated applications was developed by Dr. Henry Alberts in his work that concluded with (a) a redesign of the U. S. defense acquisition system in 1994, in collaboration with over 300 program managers; and (b) Congressional passage of the "Federal Acquisition Streamlining Act of 1994", based upon his five-year design program.

Other applications include many instances of problematique development at the Ford Motor Company (Dr. Scott M. Staley, leader); developments at the Food and Drug Administration (Dr. Alexander N. Christakis, leader); developments with a variety of tribes of Native Americans (Dr. Benjamin Broome, leader); and a variety of applications carried out across Mexico (Professor A. Roxana Cárdenas, leader and educator of others), including developments carried out in strategic planning for the State of Guanajuato by Dr. Carlos Flores and his associates.

15.0 EXORCISM AND GROUP PRODUCTIVITY

Exorcise. (1) To drive (an evil spirit or spirits) out or away by ritual prayers, incantations, etc., (2) (rare) to adjure (such a spirit or spirits) (3) to free from such a spirit or spirits.

Exorcism. (2) A verbal formula or ritual used in exorcising.

--*Webster's New World Dictionary (1993), Third College Edition, Prentice-Hall, page 477.*

While it is true, as mentioned previously, that developments involving ISM rely heavily on the mathematics of multitudes, it is equally true that such developments involve considerable knowledge of behavioral science. Some of these will be identified later. For the moment, consider the idea applied by Osborne to the process called "brainstorming", developed several decades ago. Osborne recognized a common practice in group dialog that when someone sets forth an idea which might be useful in resolving a problem, what usually happens is that someone else will immediately argue that this idea will not work and says why. Repeated instances of this tend to stifle creativity. For that reason, Osborne insisted that in brainstorming, no criticism would be allowed.

This idea is extended to a broad policy issue in connection with the use of problematiques. A well-known process called the Nominal Group Technique (NGT) is used with groups to develop the problem statements that ultimately appear in the problematique. In using NGT, the people who will eventually develop the problematique are encouraged to present to the group every problem that they can think of which relates to the situation under study. Moreover they are encouraged to clarify at length each such problem until, finally, everyone in the group professes to understand every problem. This process provides the material to be used in developing the problematique and, later, conveying its interpretation.

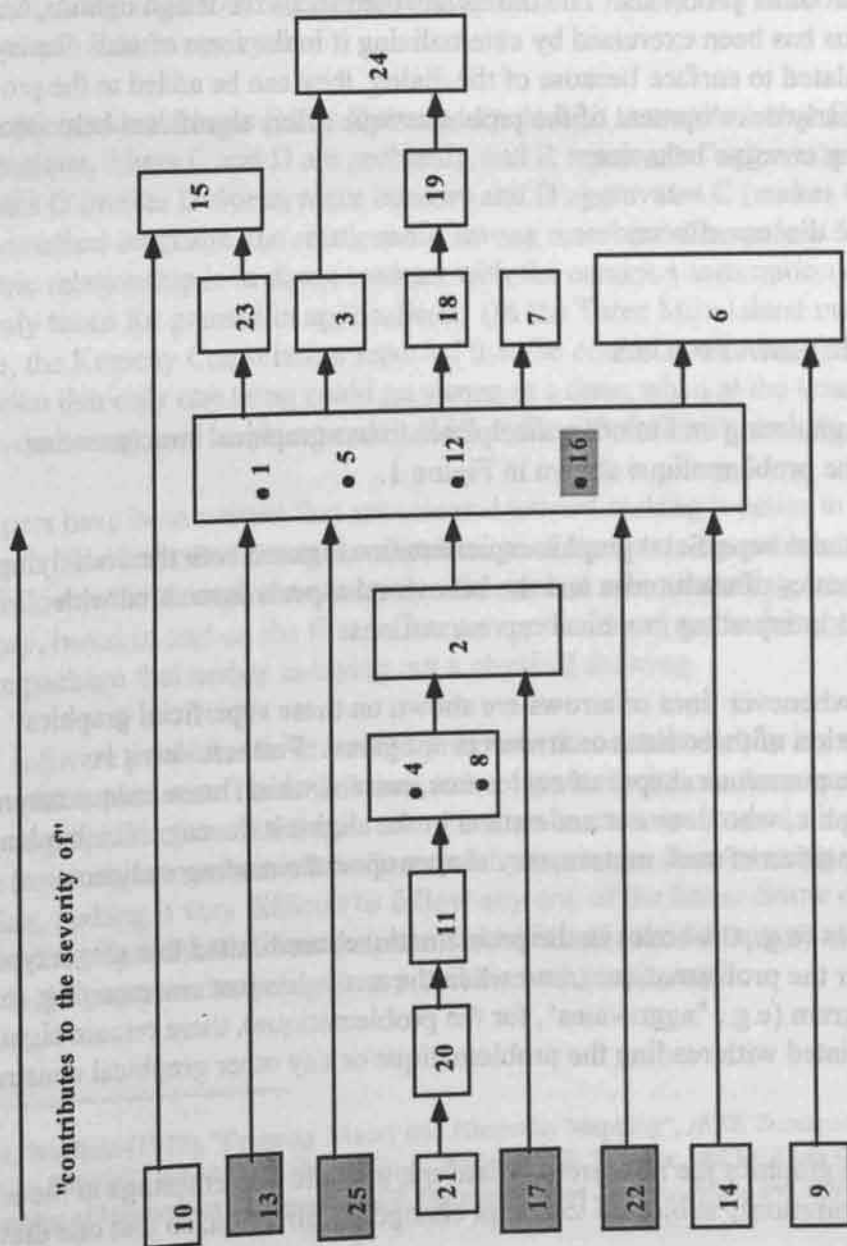


Figure 1. Structure of Problematique for John Deere pump manufacturing problem. Problem statements are represented by numbers. Shaded numbers correspond to the critical problem set, which formed the basis for resolving the pump problem. Details appear elsewhere (Warfield, 1994).

For the moment however, its value in freeing the minds of the people in the group to do constructive work is notable. The Osborne rule that no criticism is allowed is helpful in brainstorming by avoiding behavior that stifles creativity. But this rule also imposes a cognitive burden and may be frustrating to people who think that they know why certain ideas lack value. These people may feel that it is harmful to suppress their ideas because if certain ideas are retained and ultimately get accepted, this may lead to bad consequences.

When the NGT is used as mentioned above, the clarification assures that all problems which are conceived get into the considered set, and provide understanding. This frees the minds of group members to be constructive. They can use the problem set posted on the wall to stimulate their thinking about options for resolution later on, without fear of criticism leveled by people who are constantly thinking about other problems. The minds can then focus on design options, because the natural problem focus has been exorcised by externalizing it in the form of wall displays. If new problems are stimulated to surface because of the dialog, they can be added to the problems list. Thus it is felt that early development of the problematique offers significant behavioral advantages in stimulating creative behavior.

Other advantages will be discussed later.

16.0 READING PROBLEMATIQUES

It is commonplace in engineering and in other disciplines to use graphical structures that superficially resemble the problematique shown in Figure 1.

It is commonplace that these superficial graphic representations ignore both the underlying relevance of the mathematics of multitudes and the behavioral aspects associated with developing, reading, and interpreting graphical representations.

It is commonplace that whenever lines or arrows are shown on these superficial graphics structures, the interpretation of these lines or arrows is not given. Furthermore it is commonplace to involve numerous shapes of enclosures, each of which has a unique meaning to the originator of the graphic, who does not understand in the slightest the cognitive burdens associated with the imposition of such unnecessary shapes upon the reading audience.

Even when the enclosures (e.g., the boxes in the problematique) are limited to a single type of entry (e.g., problems, for the problematique), and when the arrow has just one meaning, this being shown on the diagram (e.g., "aggravates", for the problematique), there remain significant cognitive burdens associated with reading the problematique or any other graphical construction similar in extent.

Typically the superficial graphics are not carefully laid out to avoid line crossings to the extent possible, and lines are commonly subjected to abrupt changes in direction, so that one drawing

may have lines going in many directions.

Standardization of arrow usage is seldom given any attention in the superficial graphics.

Moreover, it is very common not to distinguish between hierarchical presentations and cyclic presentations. Figure 1, for example, includes two cyclic substructures ("cycles", one having 2 members and the other having 4 members). In the standardized notation of the problematique (and in other applications of ISM), cyclic substructures are readily identified by the "bullets" that appear in front of the individual members of the cycle.

In one outstanding application of ISM, extremely large cyclic substructures were identified (see Section 20, "Raymond Fitz and the Sahel Region"). It is very rare to see a problematique that does not have at least one cycle.

By definition, two elements C and D are in a cycle, if it is true both that CRD and DRC. For a problematique, where C and D are problems, and R represents "aggravates", this means that C aggravates D (makes D worse, more intense) and D aggravates C (makes C worse, more intense). In mathematical language, the relationship among members of a cycle is "symmetric". A symmetric relationship is in direct contrast with the common assumption of single causality, so commonly taken for granted in applications. (In the Three Mile Island nuclear disaster, for instance, the Kemeny Commission reported that the control room was designed under the assumption that only one thing could go wrong at a time; when at the time of this accident, three things went wrong, and no prior work had been done to deal with such an event.)

Two papers have been written that are oriented toward making it easier to read structural graphics²⁹. The first one stresses the elimination of line crossings which make it difficult for the eye to follow paths through the structure. The second one, emanating from a Fujitsu research laboratory, based in part on the first, offers an approach and methodology for developing a software package that assists in laying out a physical drawing.

Several software producers have written programs that automatically lay out problematiques and other graphic structures. These software writers typically ignore the requirements for easy visual reading of graphics. Some of them cause the lines to undergo several ninety-degree changes enroute from origin to termination. Some of them produce lines running parallel with negligible separation, making it very difficult to follow any one of the lines. Some of them fail to bring the arrows to the edge of the relevant boxes. None of them take advantage of the crossing theory offered in the paper on "crossing theory and hierarchy mapping".

²⁹ J. N. Warfield (1977), "Crossing Theory and Hierarchy Mapping", *IEEE Transactions on Systems, Man, and Cybernetics*, SMC7(7), 502-523; R. Tamassia, K. Sugiyama, S. Tagawa, and M. Toda (1981), "Methods for Visual Understanding of Hierarchical Systems", *IEEE Transactions on Systems, Man, and Cybernetics*, SMC11(2), 109-125.

In lieu of any better rule, the construction of a problematique still is best done manually, taking advantage of the material in the referenced paper. The best format for readability is the landscape format, and lines should run parallel to one another (but separated significantly) straight from left to right, with as few exceptions as possible. The addition of "dummy nodes" in particular spots, as shown in the paper on crossing theory and hierarchy mapping, will often enhance the ability to keep the lines parallel and keep the crossings to a minimum.

17.0 THE PROCRUSTES SYNDROME IN HIGHER EDUCATION

Not to be outdone by common practice, higher education also ignores the teaching of how to read structural models (probably a natural thing to do when higher education also ignores the teaching of how to construct them and, more generally, ignores design of large systems as a possible academic learning experience). This is particularly annoying in light of the fact that extensive instruction in English (or other natural languages) is carried out, such natural languages being entirely linear in usage. The problematique, like most other structural models, is non-linear, and requires a reading style quite different from that in reading natural language. Moreover, by covertly reinforcing the idea that prose is adequate to represent complexity, higher education continues to reinforce inappropriate behavioral practices that cannot be justified when dealing with complexity.

The practice of forcing all communication into a prose format is analogous to the long-known story about Procrustes. This giant operated an inn for travelers. If the traveler was too short for the bed, Procrustes stretched the traveler to produce a fit between the traveler and the bed. If the traveler was too long for the bed, Procrustes chopped off those parts of the traveler that extended beyond the bed. So it is with the constant, repetitive, virtually-unforgivable practice in academia to force students to communicate about complexity using a medium that is inherently unsuited (by itself) to do so; and then evaluating the student on criteria that are fundamentally defective³⁰ because they ignore the foundations of communication.

18.0 HYBRID STRUCTURAL MODELS

A typical structural model from an application will reveal one or more cycles, containing at least two elements. But if there are no such cycles, the model is "hierarchical". If all of the elements in a model are contained in the same cycle, the model is "cyclic". These two types, hierarchical and cyclic, are pure forms; but most structural models from applications do not correspond to either of these pure forms, so they are called "hybrid".

³⁰ More details are given in: John N. Warfield (1995), *Procrustes is Alive and Well, and is Teaching Composition in the English Department*, Fairfax, VA: IASIS.

If a structural model contains one or more large cycles (i.e., cycles having many elements), the interpretation and utility tends to suffer. For that reason, two methods have been developed to facilitate interpreting and using models that contain one or more large cycles.

19.0 THRESHOLDING AND THE HIERARCHY OF GEODETIC CYCLES

The two methods that have been developed specifically to facilitate the interpretation and use of models containing large cycles are called:

- *Thresholding Method*
- *Geodetic Cycle Method*

These methods, while rarely used, are available for use in the conditions mentioned³¹.

A notable use of the Geodetic Cycle Method occurred in the 1970's, involving a study of changing conditions in the desert of the Sahel. In this instance, the changing desert conditions produced a very large cycle.

20.0 RAYMOND FITZ AND THE SAHEL REGION

Raymond Fitz, S. M., Ph. D., of the University of Dayton, became acquainted with ISM in the 1970s, and was the leader of the first computer-assisted application ever carried out. Following that, he also provided leadership in studying a major catastrophe in the Sahel region of Africa, involving deterioration of living conditions for nomads, expansion of the desert, and loss of vegetation³².

The publication describing the large cycle and numerous subcycles is still the best work ever done to show the application of ISM to a situation represented by very large cycles. The paper illustrates also the decomposition of a very large cycle into multiple subcycles, each of which (standing alone) is representative of a particular feature of desert ecology, and corresponds to an academic specialty.

21. EARLY INTERPRETATION PRACTICES

When the problematique began to be constructed as a common aspect of the description of problematic situations, it was supposed that the participants who created it (with computer help)

³¹ Both of these methods are described in the book: John N. Warfield (1976), *Societal Systems: Planning, Policy, and Complexity*, New York: Wiley.

³² E. Zamierowski, D. Hornbach, and R. Fitz (1976), *Ecological Components of Climax Agriculture: An Example of Structuring Complex Feedback Systems*, Proceedings of the International Conference on Cybernetics and Society, New York: Institute of Electrical and Electronics Engineers, 667-673.

would be able to read the problematique and interpret it. Alas, experience has shown that most participants require help in reading problematiques and in interpreting the information contained therein.

Initially, in an effort to help readers, the problematique was explained in terms of the problems lying at opposite ends of the structure. Those at the extreme right (see Fig. 1, for example) were described as "symptomatic", and those at the extreme left were described as "fundamental". Intermediate problems were seen as being affected by those on the left, and affecting those on the right.

Later, the term "root cause" gained popularity, and some enthusiasts began to describe the elements lying at the left as the root causes of the problematic situation. (The positivistic philosophy has strong roots in social cultures.)

Neither of these early forms of interpretation was commendable. It became clear that better ways of describing and interpreting the problematique were essential.

22. COLLINGWOOD, KETNER, AND CONTEXTUAL IMPLICATION

Professor Kenneth L. Ketner of Texas Tech University holds a chair dedicated to the memory and writings of the American philosopher Charles Sanders Peirce. While doing yeoman work to expand the awareness of scholars and to emphasize the importance of Peirce's work, Ketner also has studied other philosophers. One of the reports which he produced described the Doctrine of Absolute Presuppositions, coming from the British philosopher, R. G. Collingwood³³.

He quotes Collingwood as follows:

"Whenever anybody states a thought in words, there are a great many more thoughts in his mind than there are expressed in his statement. Among these there are some which stand in a peculiar relation to the thought he has stated; they are not merely its context, they are its presuppositions."

Ketner proposes to use the term "contextual implication" introduced by Isabel Hungerford (1960, *Inquiry* 3, 211-258) to represent the ideas that are implicit in what is being stated.

The relevance of this concept to the problematique is easy to describe. The problematique shows how problems are aggravated by other problems, so to understand what is going on in a problematic situation, one needs to understand the possibly numerous conceptual antecedents to each individual problem on the problematique. These may be generated in the mind by reflecting on what seems to be taken for granted about the reader's knowledge when a statement is placed

³³ K. L. Ketner (1973), *An Emendation of R. G. Collingwood's Doctrine of Absolute Presuppositions*, Graduate Studies Number 4, Lubbock, TX: Texas Tech Press.

before the reader.

While, for some problems, antecedents will be apparent on the problematique, none are shown on the problematique for those lying at the extreme left. Does this mean that they have no antecedents? Collingwood's answer would be "no".

One may immediately become aware of the thought that for every problem lying at the extreme left of a problematique, it is possible to suppose that there is a larger problematic situation than the one studied, in which other problems may be seen as aggravating those which lie at the extreme left of the problematique. Sometimes it will be helpful to try to unearth what those unseen problems might be. One can imagine pursuing this kind of reasoning at length, and thereby encountering precisely what Collingwood was getting at in his philosophy, and what Ketner explains in his article.

No work is known to the writer where such a pursuit has been carried out with a problematique as a starting point, so perhaps the frequency with which such investigations should occur is small. Still it will be well to keep in mind this possibility, and not to preempt it by automatically assigning final significance to those problems lying at the left of the problematique.

23. DERIVING INTERPRETIVE NUMBERS FOR THE PROBLEMATIQUE

Two kinds of measures have been developed to help interpret the problematique, or to see it in an overview perspective. The first kind involves the computation for each problem of certain numerical values that can be determined from the information that defines the structure of the problematique, i.e., the **problem-specific measures**. The second kind involves the computation of values that represent measures of complexity, i.e., the **indexes of complexity**³⁴. Only the first type will be dealt with in this document.

The measures applied to a particular problem (the "reference problem") are called: Succedent Score, Antecedent Score, Activity Score, NGT Weighting Score, and Influence Score. The Succedent Score is just a count of the number of problems aggravated by the reference problem. The Antecedent Score is a count of the number of problems that aggravate the reference problem. The Activity Score is the sum of the Succedent Score and the Antecedent Score, less the number of problems that are both succedent and antecedent to the reference problem (these being found only in cycles). The NGT Weighting Score is a measure of individual voting for the reference problem, developed through the voting step of the Nominal Group Technique. The Influence Score is computed as the Succedent Score minus the Antecedent Score. The Influence Score can be positive, zero, or negative. Problems whose Influence Score are relatively large and positive aggravate quite a few other problems, but are not aggravated by many other problems. Problems whose Influence Score is zero have equal Succedent and Antecedent Scores. Problems whose Influence Score is negative and large in absolute value are primarily aggravated by other problems. Inspection of these scores makes it possible to place some problems into one or more of the following categories:

³⁴ Staley, S.M. 1995, "Complexity Measurements of Systems Design", in *Integrated Design and Process Technology*, (A. Ertas, C. V. Ramamoorthy, M. M. Tanik, I. I. Esat, F. Veniali, and Taleb-Bendiab, Editors), IDPT-Vol. 1, 153-161.

1 **CRITICAL.** This problem type has high influence, thus aggravates many other problems, and may be among the most important in terms of immediate action. **Hypothesis:** This problem type deserves immediate, high-priority attention.

2 **UNDERRATED.** This problem type has high influence, has a low NGT Weighting Score, aggravates many other problems, and was not recognized as among the most important by the group. **Hypothesis:** This problem deserves immediate, high-priority attention. The group should reevaluate the importance in the light of interactions.

3 **OVERRATED.** This problem type received a high NGT Weighting Score and a high Activity Score, but it received a low or negative Influence Score. Because it does not aggravate many other problems it is probably not as important for the moment at least, as several group members imagined. **Hypothesis:** Action on this problem should very likely be deferred until some later time.

4 **CYCLIC.** Problems in cycles aggravate each other. **Hypothesis:** Problems in cycles should be acted on collectively, and this should be recognized in team assignments.

5 **HIGH ACTIVITY.** Problems of this type are both aggravated by other problems and aggravative to other problems, even though their influence may not be high. **Hypothesis:** The interactions involving these problems should be studied in detail, and recognized in choosing personnel for task forces.

6 **HIGH-WEIGHTED PROBLEMS.** This type of problem was thought to be quite important in the NGT voting, but this voting has been shown to be unreliable. (This category overlaps with, but is not the same as category 3.) **Hypothesis:** Interactions involving these problems should be studied carefully and their importance should be reevaluated in the light of the interactions.

24. SPREADTHINK AND THE PROBLEMATIQUE

Spreadthink is the name given to a key discovery emanating from many applications of the problematique, involving many different situations and many different groups. This discovery is that individuals in the relevant groups have views on relative importance of problems that lie all over the map. There is essentially no correlation among individual views. **This discovery validates the view that situations involving complexity are fundamentally different from normal situations of the type that typically form "problems" to be solved by students engaged in higher education.**

A conclusion reached from the recognition of Spreadthink is that structural thinking is essential for purposes of attempting to resolve complex situations³⁵.

³⁵ These matters are dealt with in two papers. John N. Warfield (1995), "Spreadthink: Explaining Ineffective Groups", *Systems Research* 12(1), 5-14 and John N. Warfield and Scott M. Staley (1996), "Structural Thinking: Organizing Complexity Through Disciplined Activity", *Systems Research* 13(1), 47-67 (with correction of typographical errors in 13(2), p. 190.)

25. INTERACTIVE MANAGEMENT

The problematique is an important structural type in which ISM is applied to enable group development of a structural feature of a situation viewed as complex. The problematique is one component of a larger system for exploring and managing complexity. This larger system is called "Interactive Management"³⁶.

26. THE DEMOSOPHIA SITUATION ROOM

The development of a problematique or any other graphics-based outcomes involving Interactive Management is greatly facilitated by the availability of a situation room specifically designed to support group work involving the application of Interactive Management. This room is called "Demosophia", being derived from the concatenation of words from the Greek referring to the people and their wisdom.

Rooms of this type have been put in place at the Ford Motor Company, the Southwest Fisheries Science Center (La Jolla, CA and Honolulu, HI), and at the Instituto Tecnológico y de Estudios Superiores de Monterrey, where they are used in implementing Interactive Management and in teaching design. Rooms of this type were created, tested, and improved at the University of Virginia (1982-1983) and George Mason University (1985-1989).

27. THE PROBLEM FIELD: DUAL INDICATIONS ON THE PROBLEMATIQUE

In most of the early applications of the problematique, no effort was made to show on the problematique **categories** for problems. But one of the early users of Interactive Management, Dr. Ross Janes, City University, London, drew larger boxes around collections of problems to categorize them in various ways, as a way to enhance the interpretation of the problematique. This approach was not known to most users, and is still not widely used today, in spite of its merits in interpreting problematiques.

More recently, the concept of Problem Field was developed (Warfield, 1994). With this concept, problems are placed in categories, using ISM with groups. After the problems are placed in categories, according to their relative commonality, the categories are given names that reflect the commonality. It will usually be necessary to move a few problems manually (on the wall) from one category to another, as part of this process. Because categories are discovered based upon the outcome of application of ISM, being named only after groupings have been created,

³⁶ Interactive Management is the subject of a book called *A Handbook of Interactive Management*, co-authored by John N. Warfield and A. Roxana Cárdenas, published in 1994 by the Iowa State University Press. This book places the problematique within the larger context of a system of management designed specifically to enable organizations to work with complexity. A studied connection between Interactive Management and the Club of Rome appears in: Alexander Christakis (1987), "Systems Profile: The Club of Rome Revisited", *Systems Research* 4(1), 53-58.

the act of naming helps, iteratively, to arrive at the Problem Field.

After the problems have been categorized, it is common to assign letter indexes to the categories. This makes it possible to show, for each problem in the problematique, the letter symbol that identifies the category. An index that names the categories can normally be shown on the same page. An example of a problematique following this approach appears in Figure 2. The names of the categories are not shown, for reasons of accommodation to limited space, but the letters identify problems lying in the same category. This problematique was developed to support thought about restructuring of the positioning of military forces following the end of the "Cold War".

This method enables various discussions to take place while viewing the large wall display. These discussions facilitate interpretation of the problematique in large organizations (as discussed in Section 32).

28. USING THE PROBLEM FIELD TO TRIGGER SELECTIVE DESIGN OPTIONS

Interactive Management can be applied to develop and structure "design options" and "design alternatives", with an aim of resolving the many problems shown on the problematique. For this purpose, groups can be asked to conceive options for each of the problem categories separately, to help assure that a representatively large collection of options is developed.

29. THE RESOLUTION STRUCTURE

After a set of design options has been developed, it is possible, using ISM, to superimpose a second structure on the problematique. When this second structure is joined to the problematique, it is called a "Resolution Structure", because it shows how the implementation of particular options helps resolve the problems in the problematique.

Two ways of creating a Resolution Structure have been applied. In one of these ways, individual options are dealt with separately to show which problems in the problematique will be affected positively by implementing those options. In the second way, an "Enhancement Structure" is first created, to show how implementation of one option will help in implementing other options. Then the entire enhancement structure can be mapped onto the Problematique by using a computer program based on an algorithm given in *Societal Systems*.

30. GROUP ABDUCTION IN THE HISTORICAL FLOW OF SCIENCE

In the philosophy of Charles Sanders Peirce, all learning is presumed to be a consequence of inference. Peirce identifies three major types of inference: deductive, inductive, and abductive.

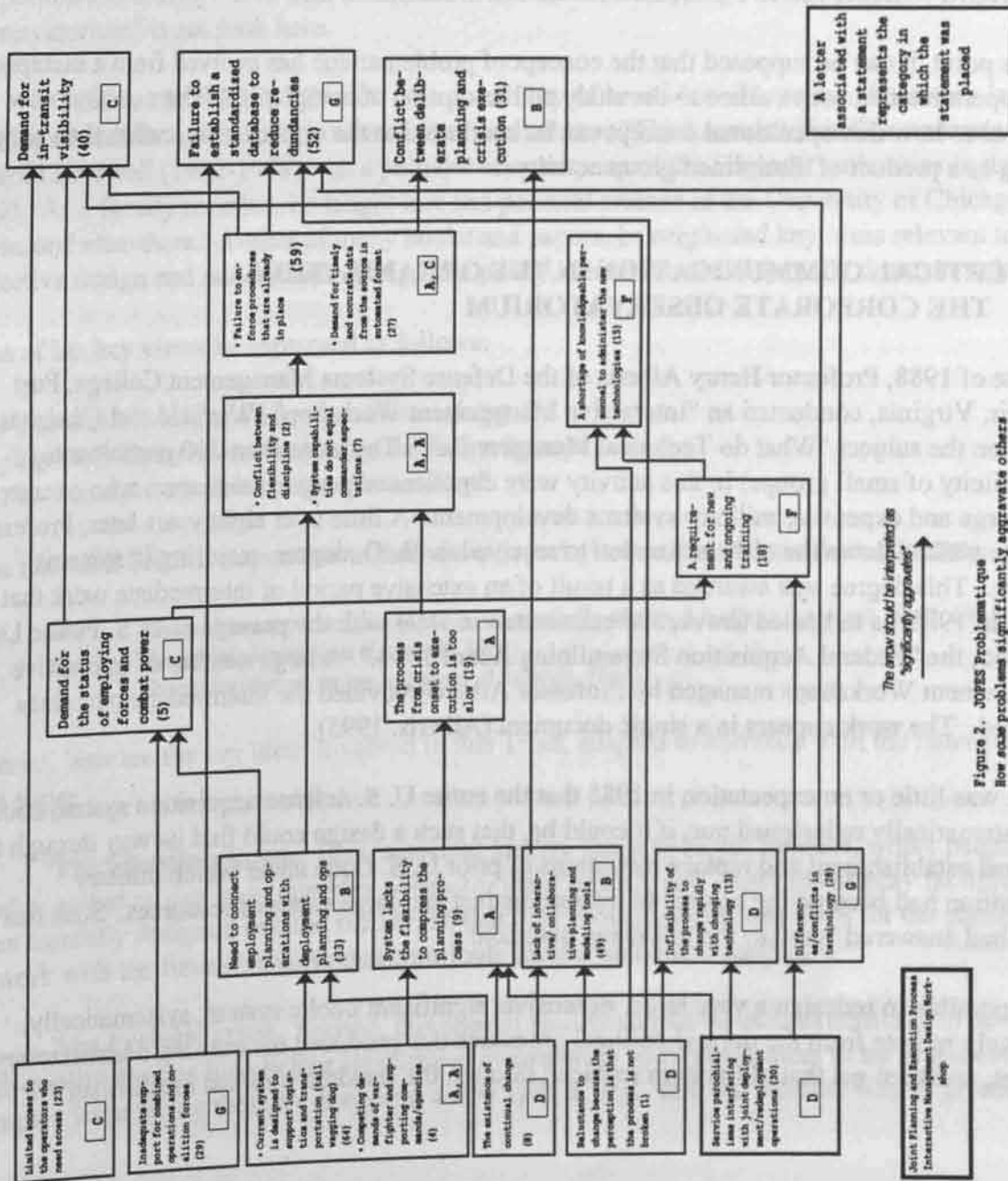


Figure 2. JOPES Problematic
How some problems significantly aggravate others

The first two are generally well known in science. The last one, abduction, was conceived by Peirce to create a name for the process of formation of hypotheses. This process typically is thought to be fundamental to support a proposal for scientific study, but Peirce could not explain how hypotheses are created.

It is felt that the group process, using ISM, which produces a problematique, can be viewed as **"group abduction"**, and that the problematique itself can be viewed both as a structural hypothesis and as a collection of hypotheses of the type illustrated in Sec. 23.

31. FROM METAPHOR TO OPERATIONAL CONCEPT

At this point, it can be supposed that the concept of problematique has evolved from a metaphor to an operational concept, allied to the study and resolution of complexity. The question now arises as to how this operational concept can be connected to the organization, rather than simply arising as a product of disciplined group activity.

32. VERTICAL COMMUNICATION IN THE ORGANIZATION: THE CORPORATE OBSERVATORIUM

In June of 1988, Professor Henry Alberts of the Defense Systems Management College, Fort Belvoir, Virginia, conducted an "Interactive Management Workshop" (Warfield and Cárdenas, 1994) on the subject "What do Technical Managers Do?" The more-than-300 participants (a multiplicity of small groups) in this activity were experienced program managers who oversee very large and expensive military systems development. A little over eight years later, Professor Alberts walked down the aisle in London to receive his Ph. D. degree, majoring in systems science. This degree was awarded as a result of an extensive period of intermediate work that began in 1988, as indicated above, and culminated in 1994 with the passage of U. S. Public Law 103-355, the "Federal Acquisition Streamlining Act of 1994." A large number of Interactive Management Workshops managed by Professor Alberts provided the intermediate outcomes required. The work appears in a single document (Alberts, 1995).

There was little or no expectation in 1988 that the entire U. S. defense acquisition system could be systematically redesigned nor, if it could be, that such a design could find its way through the political establishment and replace mountains of prior U. S. Code under which military acquisition had become the subject of intense distrust and large waste of resources. Still, this work had answered "yes" to the following question:

"Is it possible to redesign a very large, expensive, significant public system, systematically, relatively remote from the normal political processes that produced the existing unsatisfactory system, and then get that old system replaced through the standard political mechanism?"

Having observed what had to be produced to comprehend and design such a large system, inevitably serious questions ensued, of which the following is of great present interest:

"How can people learn in depth what is involved in the design, operation, and amendment of very large, expensive systems, once such a design has been completed?"

This question may, also, have a positive answer. It may well be possible for many people to learn what is involved in designing, operating, and amending such a large system and, actually to understand in depth how it works. If so, there is every reason to believe that the means of achieving this can be adapted, with minimal conceptual change, to many other systems of importance to society. It is with this belief in mind, that the concept of "corporate observatorium" is set forth here.

THE LASSWELL TRIAD. The possibility of broad-based learning about very large systems becomes more realistic when what is called here "The Lasswell Triad" is understood. Harold Lasswell (1902-1978) was a political scientist, one of the foremost authorities in that field. As a faculty member, he taught law and political science at the University of Chicago, Yale, and elsewhere. Author of many books and papers, he originated key ideas relevant to the effective design and understanding of public policy, which remain essentially dormant today.

One of his key views he expressed as follows:

"Our traditional patterns of problem-solving are flagrantly defective in presenting the future in ways that contribute insight and understanding"

The Lasswell Triad is responsive to this view, in part. It consists of these three concepts:

- The decision seminar (taking place in a specially designed facility) (Lasswell, 1960, 1971)
- The social planetarium (Lasswell, 1963)
- The prelegislature, or pre-congress (Lasswell, 1963)

In brief, here are the key ideas involved in this Triad, adapted to correlate with the latter part of this paper:

The Situation Room. First, a special facility needs to be put in place, where people can work together on design of complex policy (or other) issues, and where the display facilities have been carefully designed into the facility, so that they provide prominent ways for the participants to work with the future "in ways that contribute insight and understanding".

The Prelegislature. Second, this special facility should be used extensively to develop high-quality designs long before legislatures or corporate bodies ever meet to try to resolve some complex issue facing them by designing a new system (e.g., this is a sensible way to go about

designing a health-care system to which the political establishment can repair for insights and such modifications as seem essential).

The Observatory. Once the design has been accepted, the observatorium is designed and established so that people can walk through a sequential learning experience, in which they gain both an overview and an in-depth understanding of the system that has been designed and which, most likely, will be prominent in their own lives. The observatorium is a piece of real estate, whose building interior can be loosely compared with that of the Louvre, in that it contains a variety of rooms, and facilitates rapid familiarization with their contents by the persons who walk through that property. Further analogy comes from the recognition of the importance of wall displays (with electronic adjuncts), large enough in size to preclude any necessity to truncate communications; and tailored to help eradicate or minimize complexity in understanding, both broadly and in depth, the nature of the large organization, its problems, its vision, and its ongoing efforts to resolve its difficulties. Comparison with the planetarium for envisaging a broad swatch of the sky is self-evident.

The descriptions just given represent only modest deviations from the Lasswell Triad, but slight changes in nomenclature have been adopted for purposes of this paper. Given that relatively little has been done with the Lasswell Triad, two questions might arise. The first might be: "Why?". Another might be, "Are there additions that have to be made that, when integrated with the Lasswell Triad, provide a practical means for enhancing greatly the design, management, amendment, and understanding of large, complex systems? This last question will now be answered: "Yes".

PREPARING FOR THE OBSERVATORIUM. No one would expect that the observatorium would be brought into place unless the "art" required to fill it were available, and if the topic were of vital social importance. It would, therefore, be important to have conceived and created the situation room required for effective group work, and to have conducted the necessary prelegislative activity to provide the raw display information for the observatorium. A situation room of the type desired was developed in 1980, and has since been put into place in a variety of locations (Warfield, 1994). Rooms of this type provided the environment for the Alberts work, and for many other applications of Interactive Management (Warfield and Cárdenas, 1994). Thus the first essential preparation for the observatorium is complete. The Alberts application, and other ongoing applications have and are providing the second essential raw display information. What kinds of displays are required for the observatorium? These displays must meet stringent communication requirements. In brief, they must meet the demands of complexity for effective representation. This means, among other things, that they must be large, and they must cater to human visual requirements.

REPRESENTATION OF COMPLEXITY. The Lasswell Triad clearly relies for its adoption and use, upon the availability of ways of representing complexity that place it within the realm of human comprehension. There is a long-established penchant among scientists of all varieties to place everything possible in mathematical or numerical terms. Depending on the

specific mathematics chosen, and the numerical forms adopted, the potential learner group for such representations is greatly reduced. Does this mean that only the mathematically-educated or the numerically adept can fill effective citizenship roles in a democracy, where public understanding is necessary for good decisions? A prolonged study of complexity (Warfield, 1994) establishes that it is high-quality, graphical communication means which must be used if large, complex systems of the type studied by Alberts can be brought within the grasp of ordinary mortals.

Among the specifics in Alberts' work, lies a concept later described as "The Alberts Pattern". This pattern is a graphical inclusion structure comprised of three parts. At the lowest level, there is a set of problems developed in connection with several problematiques. This set consists of 678 problems. These problems were placed in a problems field, and located within 20 problem categories. These 20 categories were placed in a categories field, and located within 6 category areas. This three-level inclusion structure forms a key pattern for vertical communication within the Department of Defense. Persons who work with the highest structural level, who frequently discuss the 6 areas, can connect those areas to the 20 categories and to the problems in those categories. Persons who work with the lowest structural level, who frequently confront some subset of the 678 problems, can see how those are connected to the categories and areas, and then can communicate in a targeted way to persons working at higher structural levels. This can bring a considerable degree of coherence to what otherwise may be a somewhat incoherent decision milieu.

Literally dozens of such defense-acquisition-specific representations were developed by Alberts and they provide the raw material which, if introduced appropriately into a "defense acquisition system observatorium" could provide the sequenced pattern of learning that even the Congress would require in order to understand the system beyond the confines of a few of their committees. Prose alone is inadequate to portray complexity. Mathematics is often unavailable because mathematical language is restricted to a small percent of the population. For this reason, language components comprised of integrated prose-graphics representations enjoy unique potential for representing complexity. Because of the desirability of taking advantage of computers to facilitate the development and production of such integrated representations, it is best if the prose-graphics representations are readily representable in computer algorithms, even if their utility for general communication is limited. Mappings from mathematical formats to graphical formats can often be readily done, although manual modification of graphics for readability may be necessary. The following specific graphical representations have proved useful in representing complexity:

- **Arrow-Bullet Diagrams** (which are mappable from square binary matrices, and which correspond to digraphs; the problematique being a member of this type)
- **Element-Relation Diagrams** (which are mappable from incidence matrices, and which correspond to bipartite relations)
- **Fields** (which are mappable from multiple, square binary matrices, and which correspond to multiple digraphs)
- **Profiles** (which correspond to multiple binary vectors, and also correspond to Boolean spaces)
- **Total Inclusion Structures** (which correspond to distributive lattices and to power sets of a given base set)

- **Partition Structures** (which correspond to the non-distributive lattices of all partitions of a base set)
- **DELTA Charts** (which are restricted to use with temporal relationships, and which sacrifice direct mathematical connections to versatility in applications)

NEGLECT AND ABUSE OF GRAPHICS. Virtually no instruction is given in higher education even simply on how to read these high-quality, scientifically-based representations; much less on how to construct them through a disciplined process. On the other hand, it is very common to see low-quality instances of graphics types in use, where they communicate very little except, possibly, to their originators. These low-quality graphics are frequently adjuncts to a wide variety of proposed management strategies for dealing with complex situations. Over 20 of these have been discussed as "alleged panaceas" (Ackoff, 1995), who concludes that "very few of these panaceas have delivered all they promised to those who adopted them". All of the scientifically-based representational types have been thoroughly explained, and many examples of their use in a wide variety of applications are available (Warfield, 1994). Most of these types were used in the Alberts dissertation (Alberts, 1995), and can be seen there as they related specifically to defense system acquisition. The same types were used to explore in a student design course, the redesign of a large systems curriculum (Cárdenas and Rivas, 1995), and to explore high-level design activities at Ford Motor Company, where aspects of the graphics representations facilitate computation of numerical indexes of complexity (Staley, 1995).

The exploration of the large systems curriculum can, itself, be a prototype for exploitation in academia, to open up curricula (e.g., public policy curricula currently heavily oriented to "policy analysis") to activities such as large-system design.

SUMMARY. Once Interactive Management is recognized as the process system that makes possible the description, diagnosis, system design, and implementation to resolve complexity, three steps are required to take advantage of the recognition. The **first step** in resolving issues related to large, complex systems, is to provide a well-designed situation room, equipped to enable groups to work together effectively. The **second step** is to carry out whatever prolonged design work is required, using processes proven to be effective, yielding visual displays of the system patterns that hold understanding of the logic underlying the system. The **third step** is to embed the results of the second step in the corporate observatorium, where insight into the large, complex system comes both at overview and detailed levels, according to the efforts put forth to comprehend what is seen in the sequenced displays. The first two steps have been accomplished in a variety of settings. It remains to take up the challenge to develop the first corporate observatorium which may then become a prototype for its successors.

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APPENDIX 1. The Syllogism Revisited.

The developments culminating in today's problematique were described as stemming from the syllogism originated by Aristotle over 2,300 years ago.

The syllogism can be represented graphically by a linear structure comprised of three circular nodes and two arrows. The three nodes represent, respectively, statements A, B, and C. There is an arrow from A to B, representing the chosen copula, and another arrow from B to C, also representing the chosen copula.

The first arrow and the nodes to which it connects represent the statement ARB.
The second arrow and the nodes to which it connects represent the statement BRC.

The inferred third statement ARC is represented by the **directed path** originating at A and terminating at C (having passed through B on the way).

With this graphical construction in mind, one can observe that a typical problematique contains many such constructions. That is to say, **many syllogisms are combined in the single problematique.**

To get a perspective on this situation, one may count the number of distinct syllogisms represented on the problematique in Figure 2. **A total of 56 syllogisms can be found there³⁷.** This number would probably seem astonishing to all of those scholars who spent time studying the forms of a single syllogism from the time of Aristotle onward for 2 millennia! It is a testimony to the wonders of the mathematics of multitudes that such an aggregate of consistent syllogisms can be constructed for transitive relationships.

APPENDIX 2. Enhancement Structure for the Problematique

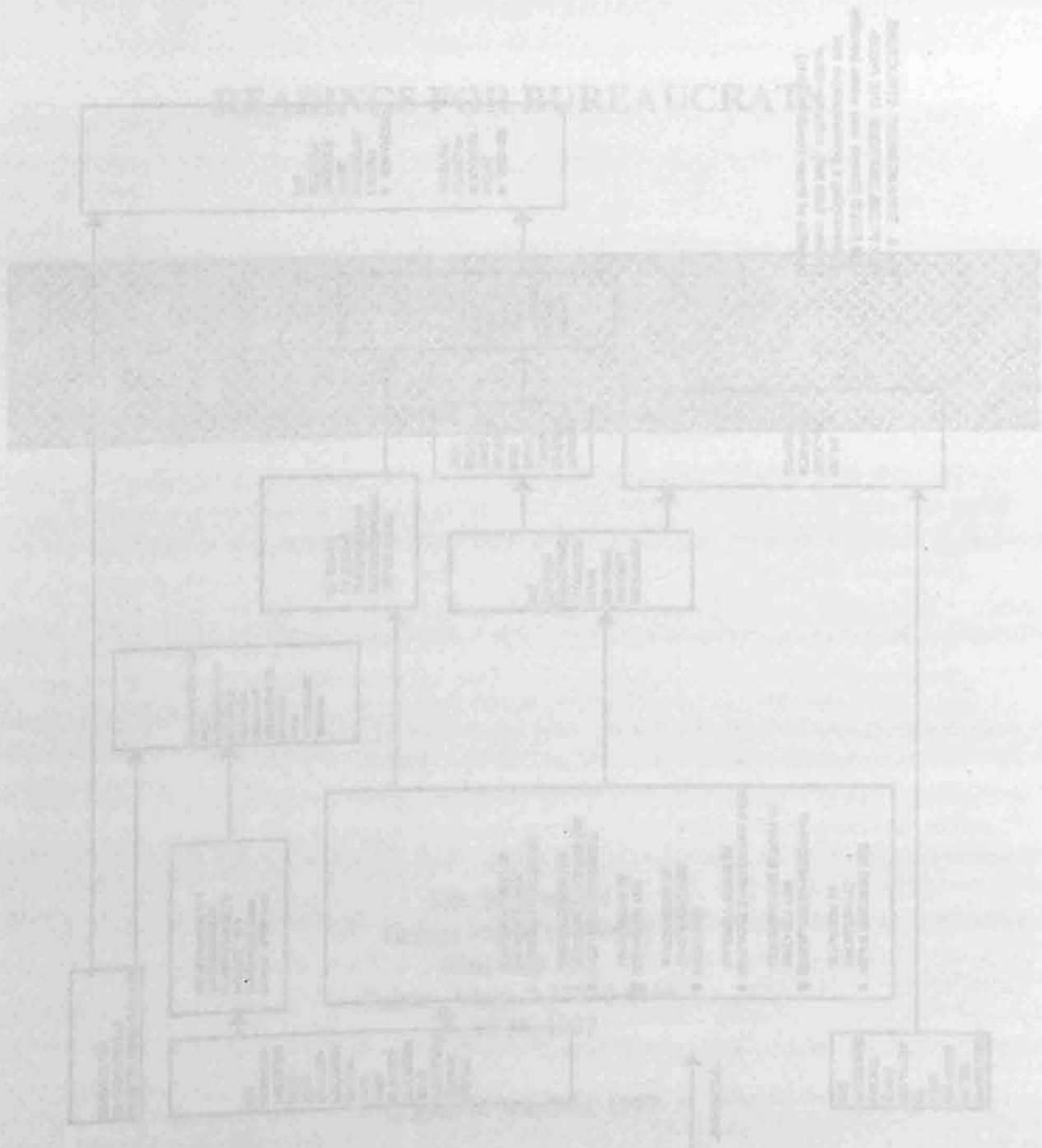
Many advantages have been claimed for the problematique. In an effort to illustrate the use of structural graphics, and to show how these advantages are related, Figure 3 has been prepared. Figure 3 is an enhancement structure for the combined use of the problematique and problem field. Benefits at the left enhance the value of benefits at the right to which they connect.

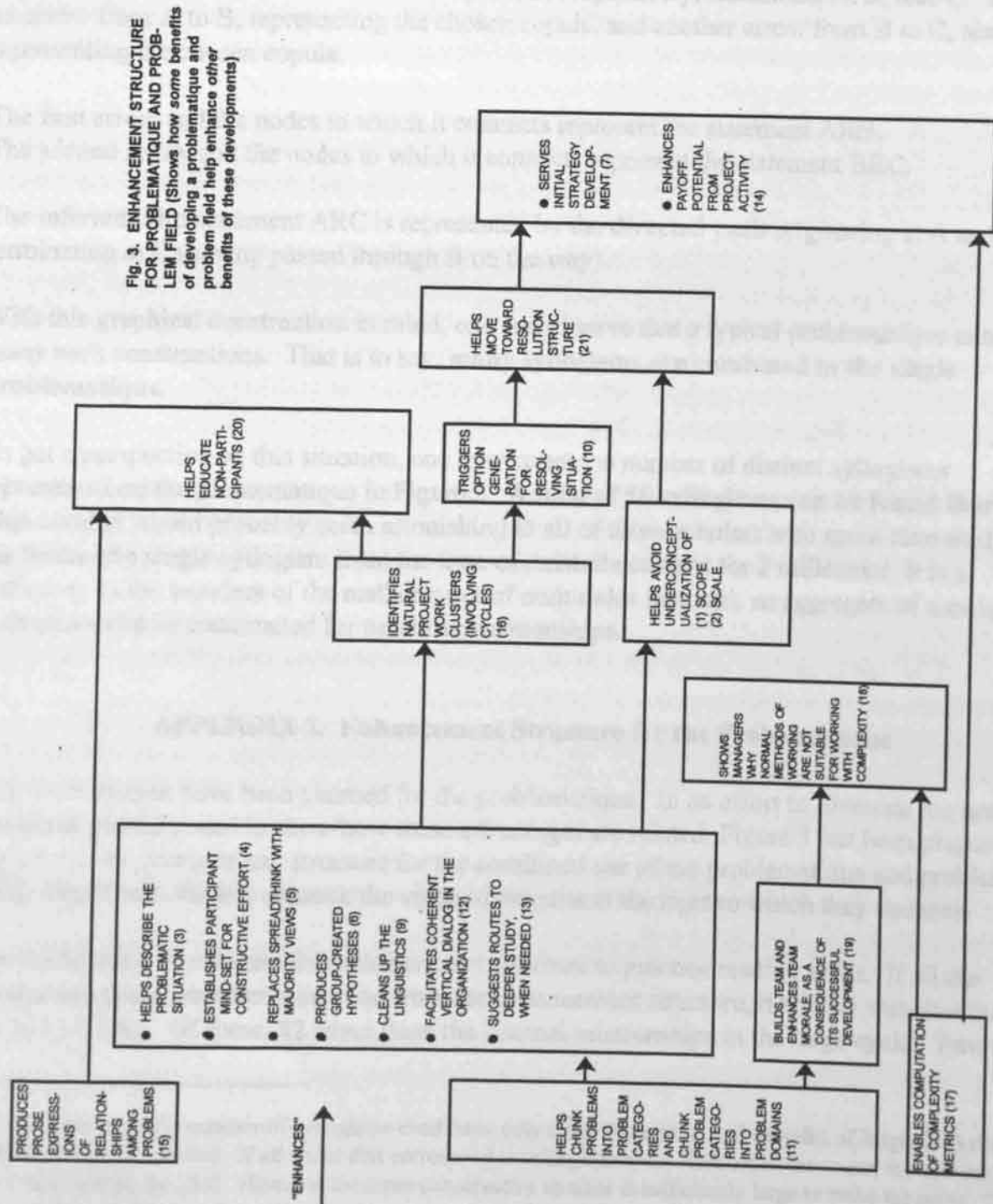
The reader may wish to use this enhancement structure to practice reading skills. If all the elementary prose statements are read from the enhancement structure, it will be seen that there are 127 of them. Of these, 42 come from the internal relationships in the large cycle. Two

³⁷ In arriving at the number of syllogisms cited here, only those that correspond to walks of length 2 on the problematique are counted. If all walks that correspond to syllogisms were included in the count, the number would grow significantly (to 324). However the more conservative number is sufficiently large to make the point. (The term "walk" and the term "length" as used here are technical terms that are defined in graph theory.)

examples of the statements are:

- The benefit "produces prose expressions of relationships among problems (#15)" enhances the benefit "helps educate non-participants (#20)".
- The benefit "helps describe the problematic situation (#3)" enhances the benefit "replaces spreadthink with majority views (#5)".

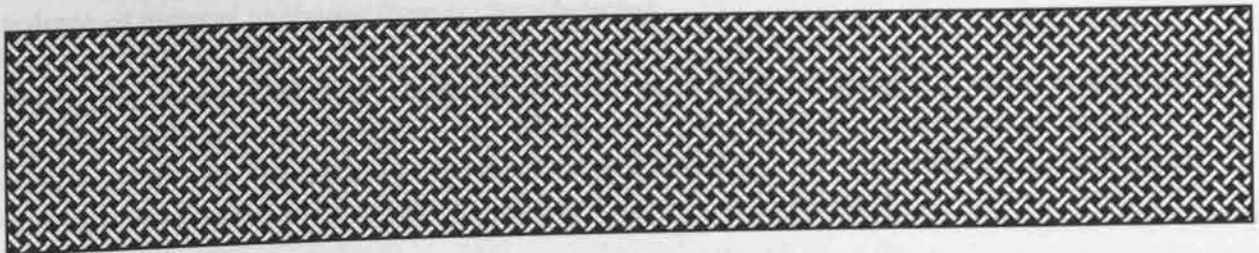




READINGS FOR BUREAUCRATS

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Bureaucrats (in government, industry, and education) are essential, pivotal actors in today's intricate world. Frequently they are overworked, and lack the time to read or study much beyond the immediate or anticipated needs of their daily work. Because they are vital players in affairs affecting many people, the potential benefits of their increased understanding are high. But the volume of material to choose from is overwhelming.

The author has been studying complexity for almost 30 years. During this period, a great deal of literature has been read¹. Now it is possible to select from that very large literature those readings which are believed to be the most valuable available. In what follows, I identify these readings, and I give a short description of why I think each is valuable.

The reader who reads only one of these will probably not gain a lot. The greatest value will come in thinking about how these readings reinforce each other: how the ideas from one merge readily with ideas from others; and how the total vision can provide a degree of coherence and a level of depth not likely to be gained in any other way. **It is not a short-term adventure.**

In what follows, the various key authors are listed in alphabetical order, and a brief discussion of the nature of their work is given. In a few instances, "Supportive References" are identified for a particular author. These support and, sometimes, extend the thinking of the key author. After the total listing concludes, a second section presents briefly a perspective on how these authors reinforce each other to yield a picture having some contemporary policy relevance.

The central message is this. There now exists a scientific basis and an implementable process, thoroughly documented and tested, for enhancing greatly the ability of people and organizations to cope with the complexity of today's society. But this basis and this process are relatively submerged by a plethora of ill-based panaceas that have much greater visibility. The steady diet of massive social waste somehow does not get connected to the use of poor processes. Perhaps if bureaucrats can be challenged to dig deeper into the fruits of history, this situation could change.

¹ At this writing, an annotated bibliography showing several hundred references can be found on the World Wide Web at this URL: http://www.statewave.com/tiers_1_4/BIBWARF.htm. Please ignore the title given there, since it does not reflect the scope of the contents.

PART 1. THE AUTHORS

■ Aristotle (384 B. C.-322 B. C.)

Aristotle I. The Categories, On Interpretation, Prior Analytics (1938 + reprints later)

Translated by H. Cooke and H. Tredennick (1983)

London: William Heinemann, Ltd.

ISBN: 0 434 99325 5 (British Edition)

In ancient times, few of the concepts that we have come to take for granted had even been identified. Here in this classical volume we see the birth of the revolutionary idea of **categories**. Also we see the birth of the **sylogism**: a 3-component bit of literary magic, showing how we can articulate a small piece of deduction; how, with two given ideas, we can infer a third.

While resting on his breaks from serving as adviser to Alexander the Great, Aristotle spent much of his time in thought, and provided the beginnings of a line of thinking about thought that are now heavily embedded in our Western ways.

With the presentation of the syllogism, scholars were engaged for well over a thousand years in examining variations of this triadic form.

Graham Wallis offered the following view of the syllogism:

"To understand what the invention of the syllogism gave to mankind we must compare it with that world of thought which it helped to supersede, the incalculable divinities, the contradictory maxims and proverbs, the disconnected fragments of observation and experience which make the apparatus of the primitive mind."

Graham Wallis (1858-1932)

The idea of categories is now so commonplace that we view categories as though they had the same kind of existence as a toothbrush, a nail, an automobile, etc. Yet, in most or perhaps all instances, categories do not exist as observable entities. You cannot photograph them, you cannot touch them, and you cannot put them on the scales. To the extent that they are thought to be real, one must begin to recognize now that there is likely to be a heavy penalty for choosing poor categories or for misusing those in common practice (see Hayek below).

I have been told that Bertrand Russell talked about "hardening of the categories" in the same way we talk about "hardening of the arteries"; i.e., a situation presaging severe difficulties, or perhaps death.

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Supportive References:

a) J. N. Warfield (1986) "Dimensionality", *Proc. 1986 International Conference on Systems, Man, and Cybernetics* 2, New York: IEEE, 1118-1121.

b) J. N. Warfield and A. N. Christakis (1987) "Dimensionality", *Systems Research* 4(2), 127-137.

A scholar of systems and cybernetics, Ross Ashby conceived the concept of "**requisite variety**". This concept seems to be very fundamental to the resolution of problematic situations. The basic idea is possibly best seen by imagining that if we want to correct reliably some undesirable situation, we have to have access to just as much variety in designing a course of action as there is in the situation we are trying to resolve.

If you think of the situation as your enemy, having a number of different lethal weapons at its disposal in trying to outwit you, you then require precisely as many countermeasures as your enemy has weapons. Imagine that the situation can defeat you even if you can overcome all but one of the weapons available to it. That one remaining can defeat you.

A real-world example of this is described by the contemporary author, Peter Senge, who talks about the advent of commercial air transportation. Several organizations were trying to come up with an airplane that had the necessary capabilities to be adequate for commercial air transportation. Imagine that the problematic situation was the enemy, and that it had four ways to prevent the achievement of a suitable aircraft. One well-known firm was able to overcome three of these, but that was not enough. Finally the Douglas company discovered how to resolve the situation by incorporating the requisite four factors in its design. What was the result? The legendary DC-3.

Staying with airplanes, suppose that you were designing a control system for an aircraft. Typically what designers do is to design for each of three possible types of motion (degrees of freedom). If you designed for control of two of them, but not for three, the airplane would probably crash. If you tried to control four or more, your aircraft design business would probably crash.

■ Bales, R. F.

R. F. Bales (1951) *Interaction Process Analysis*, Cambridge: Addison-Wesley.

Robert F. Bales was a pioneer in observing the behavior of people in groups. He found that he

could create categories of behavior and, by observing groups in action, he could categorize for each member, the type of behavior exhibited in each observable act of communication arising from each member of the group. Then he could portray the behaviors in profiles.

It was then found possible for the individual to articulate and learn about his or her own behavior, and make a conscious judgment as to whether the individual wanted to continue that type of behavior. In other words, a powerful cognitive aid to self-management came into view. While the Bales work also provided much grist for the educational mill, its potential value could be greatest in self-modification of behavior by individual persons, if only they knew how to become aware of, and interpret, their own behavior.

It would also be possible, if enough studies were done, to develop benchmark profiles (distinct from Myers-Briggs profiles) of particular kinds of people; e.g., professionals, and to judge what kinds of profiles seem to accompany various types of success or failure. In this way, broader benchmarks suitable for making educational practice decisions could evolve.

■ **Black, J. G.**

J. G. Black (1968), *The Theory of Committees and Elections*, Cambridge: Cambridge University Press.

Many things are taken for granted in this world. Yet there have been times when some of the most basic practices were questioned. In the era of the French Revolution, Condorcet studied ways of voting. Over a century later, Lewis Carroll, famous for *Alice in Wonderland*, examined many different voting schemes, and showed that every one of them could be covertly and/or conspiratorially misused by skillful manipulators.

Black studied various aspects of committees and elections and, in an appendix to his book, showed the various analyses that Lewis Carroll (a professor writing under a pen name) had constructed to show the vulnerability of the voting schemes, suggesting that these vulnerabilities could be and (on some occasions) had been exploited to circumvent the intent of the use of the voting plan.

At the very least, questions are raised here about what kinds of voting procedures should be used whenever participation is appropriate, to help assure that processes are above-board.

■ **Bochenski, I. M.**

I. M. Bochenski (1970), *A History of Formal Logic*, New York: Chelsea
(Published originally by the University of Notre Dame Press.).

A Polish priest spent many years of his life writing a history of formal logic. This history traces

mankind's efforts to learn more about how to become effective in articulating and polishing thought and reasoning, and how to make it more transparent. Beginning with writings stemming from around 400 B. C., Bochenski traces the history of developments in logic up until around 1930. To make his writing more authentic, Bochenski regularly provides quotations directly from the numerous authors that came into his purview.

It would be very hard to find a more scholarly, trustworthy book. It is truly rare to be able to get, in one book, an evolutionary overview of more than 2,000 years of history of work in a field.

Because thought is so vital in the human enterprise, it is a tragedy that so little is done in our educational system to operationalize the wisdom found in this work. It is likewise somewhat tragic to observe how little attention is given to the study of ways to enhance communication and reasoning in our educational system, based on two millennia of scholarly work.

■ **Boulding, K. F.**

Kenneth Boulding (1966) *The Impact of the Social Sciences*, New Brunswick: Rutgers University Press.

The word "beloved" is probably the most appropriate one to describe the late Kenneth Boulding. A shrewd observer of human activities, a poet, too kind to do more than hint at human frailties, Boulding was honored by repeated election to high offices in scholarly societies. Educated as an economist, he quickly rose well above that disciplinary status to be a broad thinker, and remain a good scholar. In this little book, he explains the nature of social science. He hints at its weaknesses, and makes a plea for tolerance of the practitioners of and products of social science.

■ **Braybrooke, D. and Charles E. Lindblom**

D. Braybrooke and C. E. Lindblom (1963), *A Strategy of Decision*, New York: The Free Press.

Put a philosopher and a political scientist together to talk about decisionmaking and what do you get? You get a scholarly justification for "muddling through", elevated by giving it the name of "disjointed incrementalism".

For people who work in a field loosely described as "systems science", and who advocate holistic approaches to issues, this book is anathema. It is the most tightly reasoned argument against systems thinking that is available in the literature. It is so overwhelming in its criticism that the systemists have essentially ignored the book; never responding to it, and pretending that it does not exist. Similar criticism has been offered by the constitutional scholar Laurence Tribe at Harvard University.

While the criticism is very much warranted, the work does suffer at the extremes of its depth. By

looking at matters too shallowly, it appears to be much more authoritative than it deserves to be. But its arguments are too strong to be ignored.

■ Conant, J. B.

J. B. Conant (1964), *Two Modes of Thought*, New York: Trident.

The jury is out on whether a chemist and one-time president of Harvard University, Conant's warning to America of dire consequences of continuing to confuse science with technology will bring about those consequences. Conant not only stresses the importance of seeing the clear distinction (hopefully with the idea of strengthening each of these two key areas so important to American culture and to the rest of the world), but also presents eye-catching examples of how these distinctions are reflected in human behavior. For example, the extremely different points of view of Clerk Maxwell (the British scientist of electromagnetic theory and other areas of physics) and of Thomas A. Edison (the famous American inventor and close friend of Henry Ford) dramatically demonstrate the kind of negative impact that occurs due to friction between the two groups. A similar point of view has been enunciated by Vickers (below).

But more important than the friction is the insensitivity of large sponsors of inquiry who not only confuse science and technology in the allocation of their monies, but nowadays give much more weight to visibly productive technology, threatening to eradicate by neglect the weak and over-politicized, bureaucratic, scientific establishment of America. By supposing that the rapid advance of the great American inventions is matched by advances in American science, allocators of resources not only slight science, but they display an indifference to the lessons of history of just our own twentieth century.

It has not been many years since refugees from Hitler and Mussolini came to our shores and created the inventions that helped shorten the war and save the world from further tyranny. Yet the generation of Einstein, Fermi (a major contributor to understanding the transistor), von Neumann, and others is no longer available on the American scene. The one great American scientific research institution, Bell Laboratories, has been effectively defanged by court decisions; ironically decisions that allow competitors to use the great, older products of the Bell Laboratories to gang up on AT&T in the communications business.

This is not an argument to say that the court decision was wrong. Rather it is an argument that, because of the unique nature of the Bell Laboratories, the impact of that decision might extend far beyond what Judge Greene imagined.

It may become part of the history of the ultimate decline in American science-dependent technology, just as the many bad decisions made in the past caused declines in the American steel and automotive industries.

■ **Delbecq, A. L.; A. H. Van De Ven; and D. H. Gustafson**

Group Techniques for Program Planning: A Guide to Nominal Group and DELPHI Processes (1975). Glenview, IL: Scott Foresman.

In the last half of the twentieth century, we have seen many "gurus" emerge from our business schools or from the management consulting arena. These typically relate to ways to improve the performance of organizations (one of those "categories"). It is rare to see coming from a business school a process (NGT) that is so well-designed as that one, taking account of a deep knowledge of human behavior at the individual level, and at the group level; with such strong awareness of the importance of in-depth communication and thoughtful attention to individual psyches.

The Nominal Group Technique (NGT) is the best available process for getting ideas from groups, improving the comprehension and articulation of these ideas, and making a set of ideas available for further development.

The one flaw in the process lies in its final step. The last step requires that people vote on priorities involving a large list of possible options. Other research establishes that step as flawed. If it is omitted from NGT in deference to cognitively-sensitive ways of prioritizing, all will be well with this process.

Many people who work as group facilitators do not understand this process. They think that parts of it can be changed to make it more efficient. They mistakenly believe that computerization of the process will add value to it.

■ **Downs, Anthony**

Anthony Downs (1967), *Inside Bureaucracy*, Boston: Little, Brown.

The behavior of bureaucrats as bureaucrats is predictable. This is the thesis of this book, and the author demonstrates clearly why their behavior is predictable. It is a pity that the late W. Edwards Deming did not emphasize the value of reading this book as a precursor to comprehending his valuable assertions about organizations and about quality.

As is true with Bales' work, the student of this book will find in it a number of ideas for how to modify his or her own behavior, to make the individual bureaucrat a better contributor to the effectiveness of bureaucratic organizations. The lawmaker may also find in its pages keys to how to change legislative processes; or at least to find reasons to decide that the processes should be changed, to reflect a more comprehensive view of human behavior.

■ **Etzioni, Amatai (1977-78)**

Amatai Etzioni (1977-78), "Societal Overload: Sources, Components, and Corrections", *Political Science Quarterly* 92(4), 607-631.

In our study of complexity, we have developed a set of four categories that is called "The Work Program of Complexity". This program consists of the following:

- *Description* of the problematic situation
- *Diagnosis* of the problematic situation
- *Design* of a corrective system
- *Implementation*

Description requires awareness. The strength of Etzioni's paper is that it awakens the reader to the impact of societal overload. The diagnosis is not as good as the description, but it is not bad. The weakness of the paper lies in its assumption that the social scientist is capable of singly designing the corrective system. The very factors that Etzioni's description identify are, ironically, among those that preclude a successful individually-produced design.

This paper can be read for its power to awaken.

■ **Foucault, Michel**

Michel Foucault (A. M. Sheridan Smith, Translator from the French)(1993), *The Archaeology of Knowledge & The Discourse on Language*, New York: Barnes & Noble (earlier publication in 1969 and 1971).

The French have had a lot more influence on the world than the world is prepared to recognize. (See Hayek and LeMoigne below.)

A couple of decades ago a "movement" arose in France which is now popularly called the "deconstruction" movement in America. The name of Jacques Derrida is often prominent in discussions of this movement. Another name popularly associated with it is that of Michel Foucault. Foucault, who chaired at the Collège de France the program in the history of thought, is often said to be part of this group as well.

The American academic liberal arts community deserves a thorough spanking for its allegiance to this movement, at least in part because of its misrepresentation of the movement.

Basically the movement says that most written knowledge is severely deficient, and it is time to "deconstruct" this knowledge. Going a little further, it is time to stop favoring some knowledge over other knowledge, since all of it is deficient.

Let us pose the following:

a) (Awareness.) All knowledge is deficient.

b) (Dump Mathematics and Science; Let a Thousand Flowers Bloom.) Because all knowledge is deficient, we should in our universities teach all of it and favor none of it, and, in certain areas that are more or less single-minded, such as mathematics, we should stop favoring those subjects entirely; and dispense with, or downgrade substantially, attention given in higher education to a lot of what has been enshrined, such as physics and other physical sciences.

c) (Go for High-Quality, Integrated Reconstruction). Because all knowledge is deficient, we should integrate competing clusters and upgrade the entire mix, thereby not presenting the isolated and numerous components for the poor student to cope with, but rather should structure the best from each into a newly-developed set of presentations for study and improvement. To do this, a high-quality, scientifically-based, integrative process is indispensable.

I find it easy to accept a), but only along the lines clearly laid out by Charles Sanders Peirce (see below). To me b) and c) are polar opposites. I strongly favor c), and I believe that where b) is accepted it is for bureaucratic reasons that cannot be tolerated.

Foucault himself, in this reference, presents beautifully the arguments for a); and gives many hints that the best course to pursue is c), although he does not know how to do it.

■ Goudge, T. A.

Thomas A. Goudge (1969) *The Thought of C. S. Peirce*, New York: Dover.

Some scholars are not adequately recognized during their lifetime. But sometimes, long after their demise, others begin to write profusely about their work.

The American philosopher, scientist, logician, polymath, Charles Sanders Peirce is one of those people. One of the first to write with comprehension about Peirce's work was Professor Goudge of the University of Toronto. His book offers a good initial overview. Others will be mentioned below (see Peirce).

■ Harary, Frank

Frank Harary, R. F. Norman, and D. Cartwright (1965), *Structural Models: An Introduction to the Theory of Directed Graphs*, New York: Wiley.

This book is a milestone in the history of thought. It brings together in one integrated work several branches of mathematics whose value, individually, is much less than that created when

these branches are integrated. What is integrated here is the formal logic developed over 2,000 years along with the graphical representation of patterns created from that logic. Moreover this work provides a test for the consistency of the logic displayed in the patterns.

The analytical scheme presented here laid the mathematical basis for the later development of Interpretive Structural Modeling. The latter provided the theory and algorithms needed to make possible the construction of the logic patterns described by Harary, et al.

■ Hayek, Friedrich A.

F. A. Hayek, (1955), *The Counter-Revolution of Science: Studies on the Abuse of Reason*, New York: The Free Press.

Ask American academics and business leaders this question: "Who was Hayek?"

Most American academics will probably say: "Never heard of him." Many American economists will probably say "Oh, he is that darling of the conservatives, a member of the Austrian School, whose products are mostly taught at the University of Chicago and at Auburn."

Several business leaders will have heard of him, and may even honor him.

But most of them will not know about this book, because most of Hayek's work was in economics, where he was a contemporary of the much-better-known, charismatic, and much-less-scholarly Maynard Keynes, whose views dominated American governmental economic thinking for many years (American executives like fashion accessories).

In this book, Hayek writes, with his usual in-depth documentation of sources, about the advent of the field of sociology (in France), under the impact of Henri Saint-Simon and the even greater impact of Saint-Simon's student, Auguste Comte. The views of Comte, according to Hayek, provided the conceptual basis for the rise of both communism and to a lesser extent of other totalitarian forms; and strongly influenced those better-known individuals who are usually mentioned in those arenas, such as Marx, Hegel, Hitler, etc..

Comte's intense views also greatly affected the way social scientists chose to study human organizations and individual human behaviors, and continue to do so at this late date.

This book is so well-written, and packed with so many heavy insights, that it is probably not a good idea to offer any quotations here, because they would emphasize inadequately the total importance of the work.

While Hayek was a friend of Karl Popper, the European philosopher, it appears that Hayek was not aware of the work of Charles Sanders Peirce. If he had known about Peirce's works, he could

have strengthened his work even more. (Popper himself eventually spoke highly of Peirce.)

■ Hedberg, B. L. T.

B. L. T. Hedberg, P. C. Nystrom, and W. H. Starbuck, "Camping on Seesaws: Prescriptions for a Self-Designing Organization", *Administrative Science Quarterly* 21, March, 41-65.

While it is rare to find a scholarly work in business-oriented journals, it is not impossible. Here we see a work that is both interesting and accurate in its diagnostic. The authors argue that the best way to improve organizations is to install in them processes that are sufficiently high in quality that they enable the organization to redesign itself periodically or perhaps continuously.

The prescription seems to have found a partial allegiance today. The part that was not taken seriously had to do with installing in organizations high-quality enabling processes. In place of that, we find the big accounting companies providing "reengineering" services. The idea of facilitating the internal redesign of organizations is too threatening for selfish high-level executives, who do not understand the nature of the role today's executives should be playing; as Deming has repeatedly stated.

■ Janis, I. L.

I. L. Janis (1982), *Groupthink--Psychological Studies of Policy Decisions and Fiascos*, Boston: Mifflin.

This work establishes firmly the concept of bad decision-making through the use of poor group processes. Even a very small component of the "Groupthink" concept, known as the "Abilene Paradox" has now become a part of the repertoire of the management consulting practitioners.

(1982) *Stress, Attitudes, and Decisions*, New York: Praeger.

Janis presents here in more detail the concepts of Groupthink, in relation to the general positioning of managers in organizations.

Supportive References.

G. T. Allison (1971) *Essence of Decision*, Boston: Little, Brown.

J. N. Warfield (1994) *A Science of Generic Design: Managing Complexity Through Systems Design*, Second Edition, Ames, IA: Iowa State University Press (first edition, Salinas, CA: Intersystems, 1990).

John N. Warfield and Carol Teigen (1993) *Groupthink, Clanthink, Spreadthink, and Linkthink* (1993), Fairfax: IASIS.

■ **Lala, R. M.**

R. M. Lala (1981) *The Creation of Wealth: The Tata Story*, Bombay: IBH Publishing Company.

This book is an inspirational story of how a large corporation can be built from the ground up, in the combined spirit of entrepreneurship and humanistic capitalism; and how its strengths go beyond the grasp of socialist government. The title portrays its emphasis.

■ **Lasswell, Harold**

Harold B. Lasswell (1971) *A Pre-View of the Policy Sciences*, New York: American Elsevier.

Supportive Reference:

John N. Warfield, "The Corporate Observatory: Sustaining Management Communication and Continuity in an Age of Complexity", in Tanik, M. M., et al (Eds.), *Integrated Design and Process Technology*, IDPT-Vol. 2, 1996. (Proc. Society for Design and Process Science, Austin, TX), 169-172.

The possibility of broad-based learning about very large systems becomes more realistic when what is called here "The Lasswell Triad" is understood.

Harold Lasswell (1902-1978) was a political scientist, one of the foremost authorities in that field. As a faculty member, he taught law and political science at the University of Chicago, Yale, and elsewhere. Author of many books and papers, he originated key ideas relevant to the effective design and understanding of public policy, which remain essentially dormant today.

He expressed one of his key views as follows:

"Our traditional patterns of problem-solving are flagrantly defective in presenting the future in ways that contribute insight and understanding"

The Lasswell Triad is responsive to this view, in part. It consists of these three concepts:

- The decision seminar (taking place in a specially-designed facility) (Lasswell, 1960, 1971)
- The social planetarium (Lasswell, 1963)
- The prelegislature, or pre-congress (Lasswell, 1963)

In brief, here are the key ideas involved in this Triad, adapted to correlate with material in the supportive reference.

The Situation Room. First, a special facility needs to be put in place, where people can work together on design of complex policy (or other) issues, and where the display facilities have been carefully designed into the facility, so that they provide prominent ways for the participants to work with the future "in ways that contribute insight and understanding".

The Prelegislature. Second, this special facility should be used extensively to develop high-quality designs long before legislatures or corporate bodies ever meet to try to resolve some complex issue facing them by designing a new system (e.g., this is a sensible way to go about designing a health-care system to which the political establishment can repair for insights and such modifications as seem essential).

The Observatory. Once a good system design has been accepted, the observatorium is designed and established so that people can walk through a sequential learning experience, in which they gain both an overview and an in-depth understanding of the system that has been designed and which, most likely, will be prominent in their own lives.

The observatorium is a piece of real estate, whose building interior can be loosely compared with that of the Louvre, in that it contains a variety of rooms, and facilitates rapid familiarization with their contents by the persons who walk through that property. Further analogy comes from the recognition of the importance of wall displays (with electronic adjuncts), large enough in size to preclude any necessity to truncate communications; and tailored to help eradicate or minimize complexity in understanding, both broadly and in depth, the nature of the large organization, its problems, its vision, and its ongoing efforts to resolve its difficulties. Comparison with the planetarium for envisaging a broad swatch of the sky may be self-evident.

■ LeMoigne, J. L.

Jacques Louis LeMoigne, (1981), "The Paradoxes of the Contemporary Engineer", *European Journal of Engineering Education* 6, 105-115.

LeMoigne traces the foundations of education in engineering to decisions made in France when the first civil engineering department was created. LeMoigne explains that the choice of direction was between Da Vinci's direction and the direction of Auguste Comte. Comte, he who initiated a philosophy that led to totalitarianism (see Hayek above), also won the day when it came to instruction in engineering. LeMoigne says that this same approach was exported to the United States, where it had major impact on how engineering education grew and is conducted, even today. As Hayek states, this approach got its start in the Ecole Polytechnique, (where positivism dug in and erected its as yet unbreached "Magenot Line"). So we analyze and quantify, but do not do creative designs in our engineering schools.

■ **March, J. G. and H. A. Simon**

J. G. March and H. A. Simon (1958), *Organizations*, New York: Wiley.

Described as the first book on organizations, this is a classic work which contains glimmers of the possibility of using structure-based thinking and graphics to portray the complexity of organizations.

■ **Miller, George**

G. A. Miller (1956), "The Magical Number Seven, Plus or Minus Two: Some Limitations on Our Capacity for Processing Information", *Psychology Review* 63(2), 81-97.

Supportive References::

H. A. Simon (1974), "How Big is a Chunk?", *Science* 183, 482-488.

J. N. Warfield (1988), "The Magical Number Three--Plus or Minus Zero", *Cybernetics and Systems* 19, 339-358.

I suppose that the beginning of self-enlightenment is to learn about what limits our behavior. We can learn our physical limitations by watching ourselves. We can learn by watching others that the whole species shares these, with modest gradation from one person to another, and in that way we can accept our limitations as species-related; rather than idiosyncratic.

With mental limitations, it is not so simple. Miller has told us of experiments that reveal our inability to bring into our short-term memory (our mental "scratch-pad" or analysis pad) more than about seven items. A supportive author, H. A. Simon, repeated Miller's experiments, and suggested that the number of items may be closer to five. Another supportive author, Warfield, mentioned that if you count interactions among base items in the counted set of ideas, the number of base ideas is probably three, and you use up the rest of your credit in thinking about the four possible interaction combinations.

With this contribution, Miller started a train of thought that seems to render this message: possibly groups and organizations also have verifiable limitations that ought to be considered in establishing behavioral patterns for getting high-quality work done.

■ National Society of Scholars [see the next bullet entry]

■ The New York Academy of Sciences

Paul R. Gross, Norman Levitt, and Martin W. Lewis (Eds.) (1996), *The Flight from Science and Reason*, New York: The New York Academy of Sciences, V. 775.

This book offers a collection of papers written by a variety of authors. The book describes what is seen as a dramatic deterioration in higher education, accompanied by the kind of behavior that one would expect from those who believe a) and b) under Foucault (above).

A similar argument has begun to appear in many places. To mention only one, the National Society of Scholars, Princeton, New Jersey, has published a report comparing the changes in American higher education from the base year of 1914 to the present, emphasizing the gradual reduction or elimination of subjects such as logic, history, mathematics, and physical science in deference to political correctness or driver training.

■ Peirce, Charles Sanders

C. S. Peirce, *Reasoning and the Logic of Things* (Kenneth Laine Ketner, Ed.)(1992), Cambridge, MA: Harvard University Press.

(1877) "The Fixation of Belief", *Popular Science Monthly*.

(1878) "How to Make Our Ideas Clear", *Popular Science Monthly*.

Supportive References:

Thomas A. Goudge (1969) *The Thought of C. S. Peirce*, New York: Dover.

James Hoopes (Ed.) (1991), *Peirce on Signs*, Chapel Hill, NC: University of N. Carolina Press.

Karl-Otto Apel (1981), *Charles S. Peirce: From Pragmatism to Pragmaticism*, Amherst: University of Massachusetts Press.

J. Brent (1993) *Charles Sanders Peirce: A Life*, Bloomington, IN: Indiana U. Press.

R. W. Burch (1991) *A Peircean Reduction Thesis*, Lubbock, TX, Texas Tech U. Press.

I know of no author whose work was so vast and so comprehensive that a set of 30 volumes of rather large books appears to be about the right size to encompass half of it. The Indiana University Press has, so far, produced around 6 volumes, enroute to the goal to be attained quite a few years from now.

There is probably more foundational thinking in his writings than in all the rest of the western literature combined. John Dewey, who was not that skilled in the formalisms, described his work as "a gold mine for future generations".

■ Polanyi, Michael

Michael Polanyi (1958), *Personal Knowledge*, Chicago: University of Chicago Press.

Polanyi talks about the nature of knowledge and how it might be regarded as personalized to the

individual, rather than as more-or-less-enshrined as the property of the collective. The widely-acclaimed concept of objectivity and the presumed capacity of the individual to put it on and take it off like a coat are both questioned here in a thoughtful way. The ascendancy of the collective and the concept of objectivity are both key parts of the philosophy of Comte (see above, Hayek, LeMoigne).

■ **Pope, Alexander (1688-1744)**

Alexander Pope, "An Essay on Criticism". *The Poems of Alexander Pope*, (John Butt, Ed.), New Haven: Yale University Press, 1963.

As a young man with health problems, Pope spent a lot of time studying the classics, including his time in translating Homer. In this poem he aggregates much of the wisdom of the ancients, wisdom that is still very relevant today.

Supportive Reference:

Warfield, J. N. (1995), "SPREADTHINK: Explaining Ineffective Groups", *Systems Research* 12(1), 5-14.

■ **Rukeyser, Muriel**

Muriel Rukeyser (1942, 1988 reprint), *Willard Gibbs*, Woodbridge, CT: Ox Bow.

Scholars might agree that the two greatest native-born American scientists were J. Willard Gibbs and Charles Sanders Peirce; at least among those born in the 19th century. With one studying at Harvard, the other at Yale, much of the reputation that these institutions have today might be attributed to work that they produced.

This book is a valuable biography, partly because of the insight it yields into the state of American science.

■ **Salk, Jonas**

Jonas Salk (1985), *Anatomy of Reality: Merging of Intuition and Reason*, New York: Praeger (originally published by Columbia University Press).

The late Jonas Salk, known for his work on polio vaccine, argues that major changes in society will be necessary for its survival. His proposal involves moving away from intuition only or reason only and relying, instead, on a well-arranged synergistic coupling of intuition and reason.

■ Schelling, Thomas C.

Thomas C. Schelling (1971), "On the Ecology of Micromotives", *Public Interest* 25, 61-98.

Schelling has produced a down-to-earth paper, in which he illustrates how a wide variety of minuscule actions, motivated by self-interest, regularly frustrate and impose externalized burdens on the general public.

■ Senge, Peter

Peter Senge (1990), *The Fifth Discipline: The Art and Practice of the Learning Organization*, Doubleday Doran.

In taking a step toward the incorporation of systems thinking into organizational practice, Senge has, to some extent, violated the "code of the hills", which reflects a desire to keep anything that even sounds like it might have some scientific base, out of the in-group business school literature; at least anything that might affect education in organizations and management.

At the same time, the amount of science reflected in the book is minimal, as the title itself suggests.

Senge has succeeded, where almost all other authors who write about systems have failed, in getting the attention of a large audience. The book is to deep knowledge much like surfing is to exploring sunken vessels holding buried treasure, but at least it gets people off the land and into the water. Wherever metaphors are sufficient to stir interest, this book is valuable.

■ Suppes, Patrick

Patrick Suppes (1960), *Axiomatic Set Theory*, New York: Dover.

Set theory is sometimes described as one of the three top products of mathematics. In this book, Suppes not only gives the foundations of the subject, but makes it clear that there is not a single set theory, but rather several set theories founded in different sets of assumptions.

■ Thompson, J. D.

J. D. Thompson (1967), *Organizations in Action*, New York: McGraw-Hill.

It is often said that it is not possible to predict behavior. Yet Thompson's description of organizations in action provides a strong base for making predictions about the behavior of large business organizations; much in the same vein as Anthony Downs has done (see above) with

respect to bureaucratic organizations (and especially "service" organizations, like government).

■ **Vickers, Sir Geoffrey**

Geoffrey Vickers (1983) *Human Systems are Different*, London: Harper and Rowe.

(1965, 1983) *The Art of Judgment: A Study of Policy Making*, London: Harper and Row
(original 1965, Chapman and Hall).

(1980) *Responsibility--Its Sources and Limits*, Seaside, CA: Intersystems.

Just as Kenneth Boulding was beloved, especially in America, Geoffrey Vickers was beloved and respected in England. The breadth and insights of Vickers, like those of several other authors noted in this paper, furnish a resource that is largely untapped in today's society, but which has much to offer for extending the thought processes of readers.

PART 2. AN INTEGRATIVE PERSPECTIVE ON THE AUTHORS

- **Forward Motion.** The early views of Aristotle on the categories and the syllogism flow forward in time, arising in various instances under various guises. The aspects of Aristotle's thinking on the syllogism that provided the impetus for hundreds of years of exploration in logic are seen in chronological variety in Bochenski's scholarly work.
- **Science as a Category.** The evolution of the concept of categories retained primarily the basic idea, but did not sustain the particular set of categories set forth by Aristotle. The idea of categorizing human behavioral actions in a group setting could hardly have occurred to Aristotle. According to Boulding, even the idea of social system is relatively new. The social system, itself a category, arises in thought as a unique concern in the 18th and 19th centuries. Arising contemporaneously with the enhanced concept of science, and the beginnings of sociology as set forth by Comte, the intense technological emphasis of the last half of the twentieth century is lacking in earlier centuries. It is probably for this reason that when we focus on science (a category) as distinct from technology we find not only the best treatises on science (a la C. S. Peirce), but also some of the worst (a la Comte), coming from authors born in bygone centuries.
- **Distinctions Among Categories.** When Conant finds it desirable to raise a caution flag about the failure to comprehend the deep-seated distinctions between science and technology in the 1960's, his timing seems to coincide with the rising tide of technology. Ironically his book appeared almost at the same time as the rapid ascendance of applications of the transistor--a device that has rapidly revolutionized communication and computer systems. It is ironic that this should occur, since the transistor is one of the first major inventions that could not have been created except for the microscopic level of scientific analysis that preceded its debut. (To appreciate that this is so, we can realize that the understanding of the junction in the transistor is based on the so-called Fermi-Dirac statistics; and that the diffusion equations from physics provide the essential analysis of the behavior. The technological contributions are largely related to manufacturing controls related to the distribution of minuscule amounts of impurities in a technologically-purified chemical element, and to advances in manufacturing technique at very small scale.) Still, on the technological side, the inventive ingenuity has made it possible to work with and design systems having transistors as circuit elements without being highly aware of or applying directly the underlying physics; at least in circuit applications.
- **The Loss of Visibility of Foundations.** The situation is somewhat reminiscent of what went on in physical chemistry, related to the work of Willard Gibbs, as described by Rukeyser. When asked to comment on Gibbs work, two high-level representatives of the AT&T company were quoted as follows:

"The difficulty in describing the work of Gibbs lies precisely in the fact that it is fundamental. It is like a ponderous foundation on which so great a superstructure has been built that no one notices the foundation any more unless it is specifically pointed out. We do not describe Newton's work in mechanics by citing a few phenomena of motion

and saying that Newton explained them; rather, we speak of 'Newtonian mechanics' and imply that it extends to all such phenomena. It would be equally justifiable to speak of 'Gibbsian thermodynamical chemistry.' Many a famous chemist has gladly made public announcement that his own fame rests on his verifications of the predictions of Gibbs. If I were asked to indicate how the work of Gibbs has influenced the arts of communication, I might indicate our chemical laboratories, which are staffed by chemists every one of which was partially formed by Gibbs, even though it is probable that no one of them ever saw the master."

---F. B. Jewett, of the American Telephone & Telegraph company...with Karl K. Darrow, in Muriel Rukeyser: *Willard Gibbs* (full citation above), p. 422.

- **Missing Categories in System Design.** Boulding and Ashby, both pioneers of the "systems movement", come at the modern concerns with systems (yet another category), one from the viewpoint of a social scientist, the other from the viewpoint of an enlightened engineer. Boulding is intensely aware of the shortcomings of the human side of matters, while Ashby sees clearly the shortcomings on the technological side of systems thinking. Ashby wishes to generalize his thinking about control systems to larger arenas, but without the excesses of other American engineers who, unlike Ashby, are buttoned down by Comte's legacy, laid on them by their education. While the quantitative bent in engineering has been a great boon when it comes to creating modern technological artifacts, the price has been paid on the social side. Today's software is still incredibly user-insensitive, although pressure for change has brought some improvements.
- **Influence of Constraints on Behavior.** Braybrooke and Lindblom, Miller, Downs, Polanyi, Etzioni, and Janis, each with a somewhat different slant on things, contribute strongly to the social science literature; where the distinctions among individual psychology; individual, group, or collective behavior; validity of conceptualizing; and the impact of overbearing constraint-filled environments all enter into play.

As the defective human performance in working with large systems, especially sociotechnical systems come into view, we see four significant contributions toward learning how to do things better:

- We have **Miller** telling us about constraints on the individual, Janis telling us about constraints on the group; **Thompson** and **Downs** telling us about institutionally-related constraints which can appear as organizational constraints
- On the one hand, we have **Hayek** telling us how we reached our current state, what evils accompanied the journey, and what points of view need to be continually attacked and overcome
- From another direction, **Foucault** tells us that we must do a lot better in the past, not leaving so much unsaid, and not giving so much exaggeration to ideas not adequately structured
- And from still another direction, we see the beginnings of a recognition that it is possible, in the light of what has been learned from scholars like **Bales** and **Boulding**, to take specific steps to improve human processes, by shifting the emphasis from individual

performance of the "lone wolf" type, to group activity, using a process designed to be relatively inoffensive and user friendly, along the lines illustrated by **Delbecq, Van de Ven, and Gustafson**.

With **Delbecq**, et al, looking at group collaborative work, we also approach the concept of organizational behavior. With **Hedberg**, et al; **March and Simon**; **Downs**; **Lasswell**, and **Thompson** raising our awareness of the behavior of people in large organizations, as often reflected in the behavior of the organization itself (a category, to which attributes now begin to be attached), as earlier was raised the awareness of individual behavior in a group setting as something that can be articulated, now we see the awakening of the idea that group and organizational behavior can be subjected to similarly careful scrutiny and, perhaps, enhanced significantly with the aid of well-designed group processes.

But **Hayek** and **LeMoigne** both raise in our awareness a consciousness of the history of the development of thought about the collective, and about education conditioned by the positivist paradigm, and its malevolent consequences. And **Schelling** gives us numerous illustrative examples of how individual behavior in the society often continues to be self-serving along lines that defeat concerns for the "commons". So in the same context with a growing evolutionary concern for more participative and creative work of collaborating groups, we are brought up short in recognition that the positivists are still at work, trying to take advantage of every trend that permits an opening for the quantification of all of the artifacts of society; and all in the name of "science and technology".

Vickers, recognizing the tendency to ignore the human dimensions of systems, also sets forth the theme of **Conant**, that science and technology are different, and that human systems are different from technological systems: themes that seem still to be far too muffled as we approach a new century (one which the computers seem to be having a hard time with).

A Few Themes for Thought. Five themes, interrelated, now begin to appear before us. These themes are as follows:

- The Reconciliation of Economic and Social Change with Complexity in Modern Life
- The Importance of Making the Organization More Effective
- The Flawed Educational System and its Possible Remedies
- The Rediscovery of Underused Legacy
- The Indistinct Image of Science

Concerning the first of these, entrepreneurs and capitalists everywhere can probably benefit by reading **Lala's** description of the evolution of the Tata Company in India. As to the merits or demerits of capitalism itself, no star shines brighter than that of **Hayek**, probably because **Hayek** both looked deeper, and questioned origins; something that is out of fashion in many quarters today, deconstructionism notwithstanding.

Much has been written about the second theme, and many consultants are making a living doing work with the aim cited. Often they do produce improvements but, in the light of how poorly some organizations have been managed, it is not a totally startling result that performance can be enhanced with new processes that lack a scientific basis.

My intention here is not to denigrate what the management gurus do; but one must say that if they could take the time to see not only what is being promoted, but also what is possible and what is not and why, orders of magnitude of improvement could be achieved.

Researchers **Miller** and **Janis**, from those cited above, have made clear that certain pathological conditions can, and do (much more frequently than imagined) severely limit and channel human decision-making behavior, both as individuals and in groups. Given that constraints are very likely to bound achievements, the superior ways to get improvement will be those that first identify the bounding constraints, and then find ways around them.

Concerning the flawed educational system, lately it has developed some of the same exaggerated commercial instincts that animate corporate entrepreneurs. One can value such activity, while still understanding how limiting it can be in terms of tradeoffs between short-term- and long-term improvement. The recent publication of the **New York Academy of Science** cites the severe decline, and some of the reasons behind it; which frequently relate to using the baleful (if subconscious) impact of positivism as an excuse for valueless **deconstruction**; avoiding the hard work and rewards that can accompany scientifically-based **reconstruction**.

The rediscovery of underused legacy is the only inexpensive key to resolving many of the issues of current concern. Seven milestones in the history of thought can be reviewed to see the long-term pattern of development that goes largely unused. Much of the pattern flows from **Bochenski's** work cited above, beginning with **Aristotle**, on to **Pierre Abélard**, on to **Gottfried Leibniz**, continuing with **Augustus De Morgan**, finding a pinnacle in **Charles Sanders Peirce**, and moving into the work of **Harary**. Our own contributions to the computer-assisted, group-facilitated discovery and restructuring of knowledge provide the closing link to implementation of radical improvements in the issues dealt with here².

Hand in hand with the un-blurring of the presently indistinct image of science, goes the

² For those who wish to pursue further what is discussed here, additional information is available at the following locations on the Internet: (1) <http://www.gwu.edu/~asc/warfield/>---a site that is becoming progressively more obsolete, soon to be replaced by (2) <http://www.gmu.edu/departments/tipp/Faculty/Warfield/warfield.htm> and (3) another home page, operated by Statewave, a consulting company located in Florida, which has incorporated the IASIS File (1947-1992, inclusive). This is a partial (not covering 1993-date) bibliography of references used by Warfield in his research studies on complexity. The bibliography contains short annotations for cited references. A printout of this bibliography requires 80 pages. The Statewave management elected to title the Bibliography as follows: "Systems Engineering Bibliography" John N. Warfield. Their choice does not accurately reflect the contents. The Statewave organization is an engineering organization, and chose that title because they believe (accurately) that many of the cited documents have relevance to systems engineering.

development of understanding of the philosophy and thoughts of **Charles Sanders Peirce**. Here is the person to whom **Gibbs** turned to review **Gibbs'** development of vector analysis; probably because **Gibbs** knew that **Peirce**, possibly alone among the rest of the native scientific establishment, comprehended what was going on in science and; more importantly, understood deeply the nature of science. This legacy has been forgotten or possibly not learned, but it is readily available to those who will look for it. In the modern era, a few writers, such as **Suppes**, have understood the importance of the legacy, and contributed to its integrative articulation.

A Poetic Vision. In closing this essay, I note that almost 300 years ago the British poet, **Alexander Pope**, encompassed in parsimonious language, and in an integrated way, many of the ideas mentioned here in his famous "**An Essay on Criticism**". I leave a challenge to the reader to muse on that literary masterpiece, and take on the task of correlating what is said here and in the references with the contents of that work.



ABSTRACT

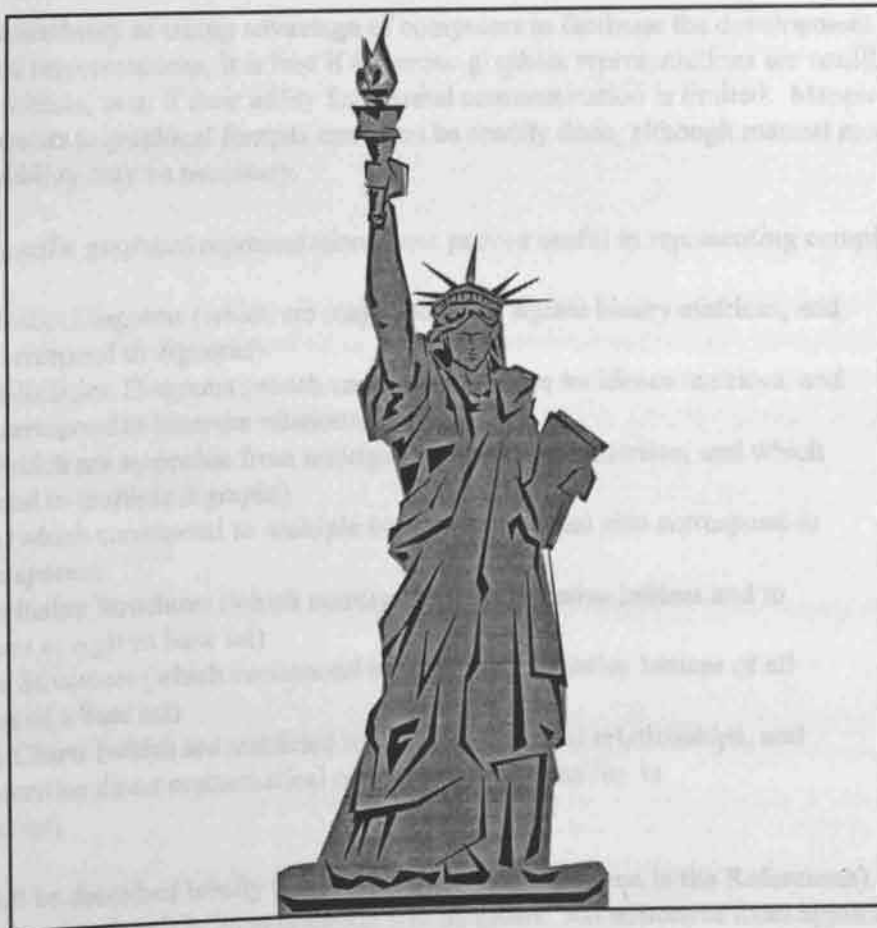
SEVEN WAYS TO PORTRAY COMPLEXITY

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"sum, ergo cogito"

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SEVEN WAYS TO PORTRAY COMPLEXITY

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1992
Paper 7/19/92 11:44



"Statue of Liberty"

Statue of Liberty

ABSTRACT

SEVEN WAYS TO PORTRAY COMPLEXITY

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Prose alone is inadequate to portray complexity. Mathematics is often unavailable because mathematical language is restricted to a small percent of the population. For this reason, language components comprised of integrated prose-graphics representations enjoy unique potential for representing complexity.

Because of the desirability of taking advantage of computers to facilitate the development and production of such integrated representations, it is best if the prose-graphics representations are readily representable in computer algorithms, even if their utility for general communication is limited. Mappings from mathematical formats to graphical formats can often be readily done, although manual modification of graphics for readability may be necessary.

The following specific graphical representations have proved useful in representing complexity:

- Arrow-Bullet Diagrams (which are mappable from square binary matrices, and which correspond to digraphs)
- Element-Relation Diagrams (which are mappable from incidence matrices, and which correspond to bipartite relations)
- Fields (which are mappable from multiple, square binary matrices, and which correspond to multiple digraphs)
- Profiles (which correspond to multiple binary vectors, and also correspond to Boolean spaces)
- Total Inclusion Structures (which correspond to distributive lattices and to power sets of a given base set)
- Partition Structures (which correspond to the non-distributive lattices of all partitions of a base set)
- DELTA Charts (which are restricted to use with temporal relationships, and which sacrifice direct mathematical connections to versatility in applications)

Each of these will be described briefly (detailed descriptions are given in the References), and at least one example of the use of each in an application will be given. All structures from applications were developed participatively by persons intimately engaged with the relevant issues.

SEVEN WAYS TO TORTURE COMPLEXITY

John A. Wray
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This paper is intended to provide a simple, practical, and often surprising means of reducing the complexity of a system. It is not a "cookbook" for the system designer, but a collection of ideas and techniques that can be used to reduce the complexity of a system.

The idea of the complexity reduction is to compare the complexity of a system to the complexity of a system that is simpler. If the complexity of a system is greater than the complexity of a simpler system, then the system is more complex. The idea is to reduce the complexity of a system by making it simpler.

The following are the seven ways to reduce complexity:

1. Reduce the number of components.
2. Reduce the number of connections.
3. Reduce the number of states.
4. Reduce the number of inputs.
5. Reduce the number of outputs.
6. Reduce the number of feedback loops.
7. Reduce the number of control loops.

Each of these will be discussed briefly. The first two are given in the Introduction, and the last five are given in the body of the paper. All systems have complexity, and the goal is to reduce it.

A NEW INDEX OF COMPLEXITY: The Aristotle Index

John N. Warfield

June 17, 1997

"To understand what the invention of the syllogism gave to mankind we must compare it with that world of thought which it helped to supersede, the incalculable divinities, the contradictory maxims and proverbs, the disconnected fragments of observation and experience which makes the apparatus of the primitive mind."

---Graham Wallas (1858-1932)

An additional index of complexity is proposed³. It will be called the "Aristotle Index", because (a) Aristotle originated the syllogism, (b) what the index measures is the number of syllogisms contained in a problematique, and (c) because the problematique portrays complexity in a problematic situation. What I want to show first are some aids in counting the number of syllogisms contained in a given problematique. Then I want to give the details of the count for the JOPES Problematique (Figure 1), as an illustrative example.

■ Counting in a Cycle.

A cycle is a set of mutually related (symmetrically related) elements. How many syllogisms are contained in a cycle?

Three elements are required to create a syllogism, so there will not be any syllogisms in a cycle that doesn't have at least 3 elements.

I will use the notation $A(n)$ to represent the number of syllogisms in a structure having n members. For a cycle,

$$A(0) = A(1) = A(2) = 0 \quad (1)$$

The general formula for computing the number of syllogisms in a cycle for n greater than or equal to 3 is as follows:

$A(n) = P(n,3)$ = the number of permutations of n things taken 3 at a time, which is computable from the well-known formula:

$$P(n,k) = n!/(n-k)! \quad (2)$$

³ Four previously-discovered indexes of complexity are described in the paper: S. M. Staley, "Complexity Measurements of Systems Design", in *Integrated Design and Process Technology*, (A. Ertas, C. V. Ramamoorthy, M. M. Tanik, I. I. Esat, F. Veniali and Taleb-Bendiab, Editors), IDPT-Vol. 1, 111-116.

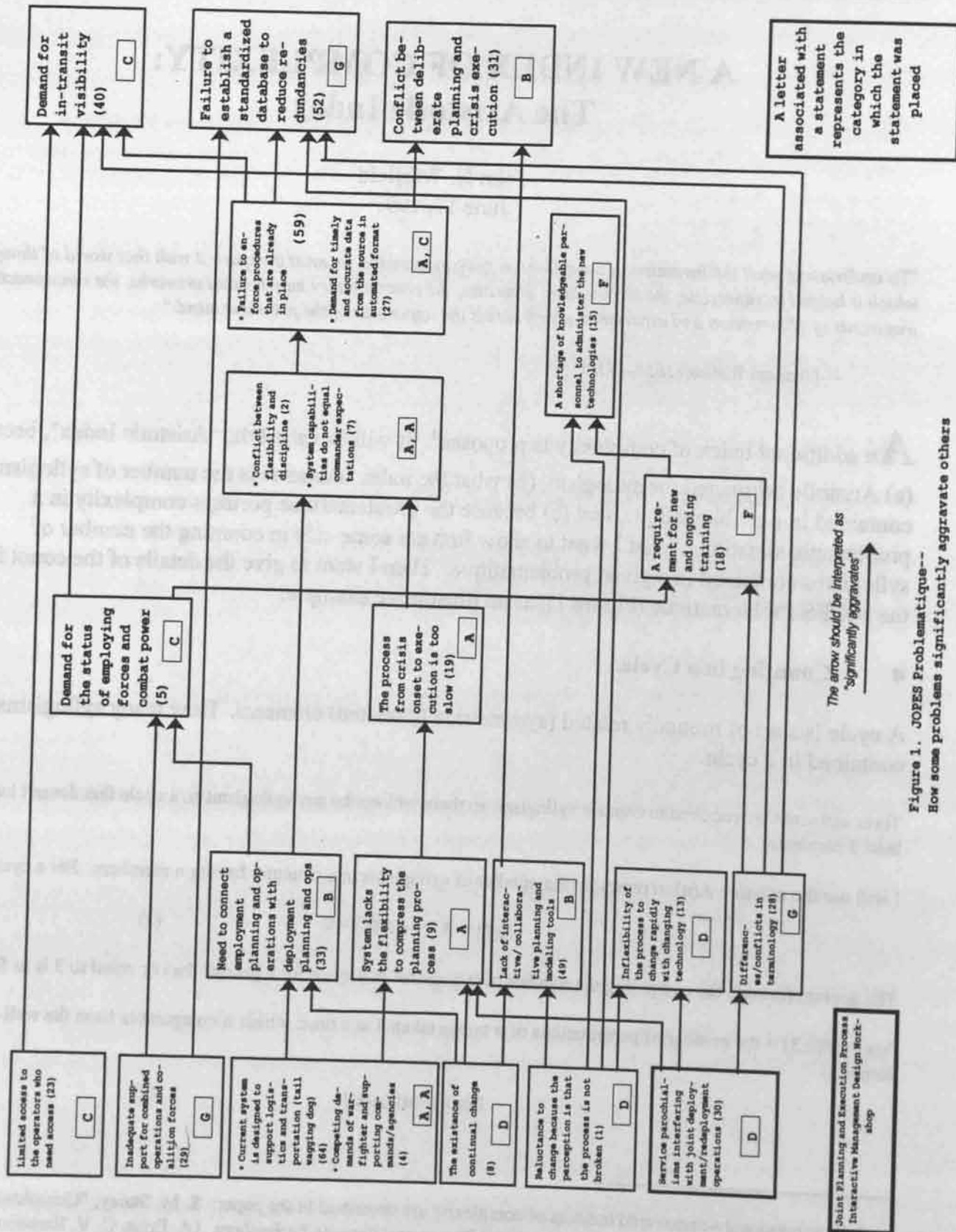


Figure 1. JPES Problematic--
How some problems significantly aggravate others

From Eq. (2), we can evaluate $P(3,3)$:

$$P(3,3) = 6 \quad (3)$$

This gives us a starting value for use in applying a recursion equation. From Eq. (2) we can derive the following recursion equation for n greater than 3:

$$P(n,3) = n/(n-3) \times P(n-1,3) \quad (4)$$

With Eq. (4), it is relatively easy to compute Table 1.

From Table 1, we see the remarkable number of syllogisms contained in cycles of moderate size. If Aristotle could see this Table, he would probably be somewhat surprised. Even a cycle with only 4 elements represents 24 syllogisms!

TABLE 1. Values of $A(n)$ for n in the range [3,20], when the structure is a cycle containing n elements.

n	$A(n)$	n	$A(n)$
3	6	12	1320
4	24	13	1716
5	60	14	2184
6	120	15	2730
7	210	16	3360
8	336	17	4080
9	504	18	4896
10	720	19	5814
11	990	20	6840

■ Counting in a Linear Hierarchy.

A linear hierarchy consists of n elements, arrayed on a line, with each element except the first having one entering arrow, and each element except the last having one leaving arrow. For this type of structure, computation of the number of syllogisms is fairly straightforward.

As was also true for the cycle,

$$A(0) = A(1) = A(2) = 0 \quad (5)$$

For $n = 3$, we have, by direct counting,

$$A(3) = 1 \quad (6)$$

We can use the following recursion equation to compute $A(n)$ for n greater than 3:

$$A(n) = A(n-1) + (1/2)(n-1)(n-2) \quad (7)$$

With Eq. (7) we can compute Table 2.

TABLE 2. Values of $A(n)$ for n in the range [3,20], when the structure is a linear hierarchy containing n elements.

n	A(n)	n	A(n)
3	1	12	220
4	4	13	286
5	10	14	364
6	20	15	455
7	35	16	560
8	56	17	680
9	84	18	816
10	120	19	969
11	165	20	1140

■ Example of Counting for the "JOPES Problematique" (Fig. 1).

The JOPES Problematique was constructed using the Interactive Management system. The participants in the construction were mostly government executives, and the work was done to meet the needs of the Joint Chiefs, a group of high-level U. S. military personnel. This structure can be used to show an example of counting in a problematique which, like most, is neither a single cycle nor a linear hierarchy, but rather is a hybrid structure. For this problematique, I systematically identify those syllogisms starting from each of the chosen problem boxes. I note that some boxes do not originate a syllogism (when there are only two boxes connected).

The syllogisms are identified by a sequence of 3 numbers, each of which represents correspondingly numbered items on the problematique. The copula (relationship) is "aggravates".

● Syllogisms Starting from Boxes 23, 49, 13, 18, 15, 40, 31, and 52.

There are no syllogisms starting from any of these boxes.

● **Syllogisms Starting from Box 29 (4).**

29,5,18
29,5,15
29,5,40
29,18,15

● **Syllogisms Starting from the Cycle Containing 4 and 64 (124).**

4,64,33
4,64,9
4,64,5
4,64,19
4,64,18

4,64,15
4,64,2
4,64,7
4,64,59
4,64,27

4,64,40
4,64,52
4,64,31
64,4,33
64,4,9

64,4,5
64,4,19
64,4,18
64,4,15
64,4,2

64,4,7
64,4,59
64,4,27
64,4,40
64,4,52

64,4,31
4,33,5

4,33,18
4,33,15
4,33,2

4,33,7
4,33,59
4,33,27
4,33,40
4,33,52

4,33,31
64,33,5
64,33,18
64,33,15
64,33,2

64,33,7
64,33,59
64,33,27
64,33,40
64,33,52

64,33,31
4,9,19
4,9,2
4,9,7
4,9,59

4,9,27
4,9,40
4,9,52
4,9,31
64,9,19

64,9,2
64,9,7
64,9,59
64,9,27
64,9,40

64,9,52

64,9,31	4,2,52
4,19,2	4,2,31
4,19,7	64,2,7
4,19,59	64,7,2
	64,2,59
4,19,27	
4,19,40	64,2,27
4,19,52	64,2,40
4,19,31	64,2,52
64,19,2	64,2,31
	4,7,59
64,19,7	
64,19,59	4,7,27
64,19,27	4,7,40
64,19,40	4,7,52
64,19,52	4,7,31
	64,7,59
64,19,31	
4,5,18	64,7,27
4,5,15	64,7,40
4,5,40	64,7,52
4,18,15	<u>64,7,31</u>
64,5,18	
64,5,15	
64,5,40	
64,18,15	
4,59,27	
4,27,59	
4,59,40	
4,59,52	
4,59,31	
64,59,27	
64,27,59	
64,59,40	
64,59,52	
64,59,31	
4,2,7	
4,7,2	
4,2,59	
4,2,27	
4,2,40	

● Syllogisms Starting from Box 8 (50).

8,33,5
8,33,2
8,33,7
8,33,27
8,33,59

8,33,40
8,33,31
8,33,52
8,33,18
8,33,15

8,9,19
8,9,2
8,9,7
8,9,59
8,9,27

8,9,40
8,9,52
8,9,31
8,49,31
8,5,18

8,5,15
8,5,40
8,19,2
8,19,7
8,19,59

8,19,27
8,19,40
8,19,52
8,19,31
8,59,27

8,59,40
8,59,52
8,59,31
8,27,59
8,27,40

8,27,52

8,27,31
8,18,15
8,2,7
8,2,59

8,2,27
8,2,40
8,2,52
8,2,31
8,7,2

8,7,59
8,7,27
8,7,40
8,7,52
8,7,31

● **Syllogisms Starting from Box 1 (1).**

1,49,31

● **Syllogisms Starting from Box 30 (40).**

30,28,18

30,28,15

30,28,52

30,28,40

30,9,19

30,9,2

30,9,7

30,9,27

30,9,59

30,9,40

30,9,31

30,9,52

30,18,15

30,19,2

30,19,7

30,19,27

30,19,59

30,19,40

30,19,31

30,19,52

30,2,7

30,2,27

30,2,59

30,2,40

30,2,31

30,2,52

30,7,2

30,7,27

30,7,59

30,7,40

30,7,31

30,7,52

30,27,59

30,27,40

30,27,31

30,27,52

30,59,27

30,59,40

30,59,31

30,59,52

● **Syllogisms Starting from Box 33 (24).**

33,5,40	33,7,52
33,5,18	33,27,40
33,5,15	33,27,31
33,18,15	33,27,52
33,2,7	33,27,59
33,2,17	33,59,40
33,2,59	33,59,31
33,2,40	33,59,52
33,2,31	<u>33,59,27</u>
33,2,52	
33,7,2	
33,7,27	
33,7,59	
33,7,40	
33,7,31	

● **Syllogisms Starting from Box 9 (27).**

9,19,2	9,7,59
9,19,7	9,7,40
9,19,27	9,7,31
9,19,59	9,7,52
9,19,40	9,27,59
9,19,31	9,27,40
9,19,52	9,27,31
9,2,7	9,27,52
9,2,27	9,59,27
9,2,59	9,59,40
9,2,40	9,59,31
9,2,31	<u>9,59,52</u>
9,2,52	
9,7,2	
9,7,27	

● **Syllogisms Starting from Box 28 (1)**

28,18,15

● **Syllogisms Starting from Box 5 (1).**

5,18,15

● **Syllogisms Starting from Box 19 (20).**

19,2,7	19,7,31
19,2,27	19,7,52
19,2,59	19,27,59
19,2,40	19,27,40
19,2,31	19,27,31
19,2,52	19,27,52
19,7,2	19,59,27
19,7,27	19,59,40
19,7,59	19,59,31
19,7,40	<u>19,59,52</u>

● **Syllogisms Starting from the Cycle Containing 2 and 7 (26).**

2,7,27	7,2,27
2,7,59	7,2,59
2,7,40	7,2,40
2,7,31	7,2,31
2,7,52	7,2,52
2,27,59	7,27,59
2,27,40	7,27,40
2,27,31	7,27,31
2,27,52	7,27,52
2,59,27	7,59,27
2,59,40	7,59,40
2,59,31	7,59,31
<u>2,59,52</u>	<u>7,59,52</u>

● **Syllogisms Starting from the Cycle Containing 27 and 59 (6).**

27,59,40	59,27,40
27,59,31	59,27,31
<u>27,59,52</u>	<u>59,27,52</u>

■ **The Aristotle Index for the JOPES Problematique.**

To determine the Aristotle Index for the JOPES Problematique, it is only necessary to add the total number of syllogisms, i.e., the numbers appearing in parentheses at the end of the various headings above.

Specifically, for the JOPES Problematique (in the order presented above):

$$A = 4 + 124 + 50 + 1 + 40 + 24 + 27 + 1 + 1 + 20 + 26 + 6 = 324.$$

What this means is that there are ³²⁴221 syllogisms embedded in the JOPES Problematique. Every one of them is of the form:

If	A R B
and	B R C,
then	A R C.

Needless to say, the prospects for any single human being or any group, acting without computer assistance, to produce 324 intertwined syllogisms, are very poor. Still, the computer is able not only to assist the group to produce such a structure, but it is also able to ensure the consistency of the logic, through the application of the relevant Boolean matrix equations.

It is also true that there is no assurance that the 324 syllogisms are all valid, because the validity of each depends upon the validity of the first two contained propositions. If the first two propositions are correct, then necessarily the final one is correct, assuming that the relationship is transitive.

■ **Structural Hypothesis and Individual Component Hypotheses.**

Because the integrity of the structure depends on the validity of the first two propositions in every one of the 324 syllogisms, it is best to think of the structure as a **structural hypothesis**, from which many **individual component hypotheses** can be constructed. Wherever there is uncertainty about any matter in the structure, all of the power of scientific inquiry can be brought to bear upon that matter, using whatever methodology is deemed appropriate (statistics, differential equation models, questionnaires, etc.); and wherever there is strong belief in already-explored ideas, no further investigation may be required.

When further investigation is required, one may suppose that it will be very valuable to the inquirer, in formulating an inquiry strategy, to see the uncertainty embedded in the tight logical context of the problematique; since this will help in formulating the inquiry that is needed to give more credibility or greater assurance to such matters.

■ **Saliency of the Foregoing to the "Real World".**

If there are readers who are not familiar with the history and practice of Interactive Management, they may believe that the foregoing is not very salient to the "real world". In deference to that point of view, it can be said that during more than 15 years of application of Interpretive Structural Modeling to the production of problematiques, there has never been an instance where the group which produced a problematique could find more than a very small number of amendments to be made. The norm is that no amendments are made.

It is a property of ISM that for structures produced using it, including the problematique, the logic is consistent. Consistency and accuracy are not necessarily the same. Accuracy has to do with whether the contents of the relationship statements that go into the structural formation are correct. Peirce gave the name "necessary inference" to the application of transitivity to produce inference.

It is possible that all of the statements are wrong, but the logic will still be consistent, because the accuracy of statements and the validity of the algebra of logic are two completely different things.

The key point is that if humans make mistakes, they will make them no matter what process is used. But if humans agree on the accuracy of statements, it seems that it would be well to have those statements consistent with one another. Otherwise, why bother reasoning at all?

A few critics will raise Emerson's famous remark that "a foolish consistency is the hobgoblin of small minds". The fact is that anything foolish is foolish, by definition. Emerson did not speak of consistency in general, but only of a "foolish consistency".

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