WHAT QUESTIONS HAVE BEEN FORMULATED AND ANSWERED IN A 30-YEAR RESEARCH PROGRAM TO STUDY

COMPLEXITY?

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ABSTRACT

A research program was initiated in 1968 to study complexity. It was intended that the study would span the landscape of complexity, from the most fundamental scientific basis to the most demanding applications in society. Thirty years later, in 1998, with much documentation available in numerous locations, the highlights of this research activity can be presented as the response to a variety of questions.

To facilitate the sequential presentation of the questions and responses, four categories are used to "house" the sequence. These four categories were found by examining about 600 transparencies that had been developed in the past 10 years of work, and placing them into 110 intermediate categories, then placing those into 10 categories, and finally placing the 10 into the 4 used here as headings. The four headings are:

Part 1. Infrastructure of Science. Under this heading one finds the key linguistic aspects related to organizing complexity, the mathematics of structure, the faulty assumptions that prevent organizations from working effectively with complexity, the contributions of thought leaders from the past, the schools of thought that are most prominent, and software for structuring complexity.

Part 2. Science of Complexity. Under this heading one finds discussion of issues related to science, the seven ways of portraying complexity, a mention of the 20 Laws of Complexity, the metrics for measuring complexity, some applications information, and a discussion of the infrastructure needed to work with complexity in organizations.

Part 3. Applications of the Science of Complexity. Under this heading one sees the Work Program of Complexity, the Behavioral Allocation Menu relating to what actors should carry out what components of the Work Program, behavioral pathologies, typical products from the components of the Work Program, aspects of design, the shared linguistic domain, and an explanation of how practitioners benefit from learning the Infrastructure of Science.

Part 4. Site of Applications (The Organization). Issues related to applications infrastructure are discussed here, along with Interactive Management (the system designed specifically to resolve complexity in organizations), some examples of how it has been used, more about the metrics of complexity, issues related to the interpretation of the structural models, vertical coherence in organizations, and strategies for enhancing organizational performance.

QUESTIONS RESOLVED IN STUDYING COMPLEXITY
1968-1998
John N. Warfield

Part 1. Infrastructure of Science

1. What are the key structural attributes of prose?

Linearity in sequencing, parallel in generating words.

2. Why is prose completely inadequate as a portrayal language for complexity?

Research shows that structures of complexity are non-linear, hence they are structurally incompatible with the constraints invoked by prose.

3. Is mathematics appropriate as a language to portray complexity?

George Friedman's Findings About the Equations of Physics

Friedman found that the average number of **variables** in an equation of physics is 4, and the maximum is 7. The number of **problems** in a typical problematic situation approaches 100.

Benjamin Peirce's Definition of Mathematics: its Relevance to Structure

Peirce defined mathematics as the science of necessary conclusions.

While the language of mathematics is appropriate for representing aspects of complexity in a restricted way, the best component of mathematics for representing complexity is not the commonly used mathematics of physics. Research shows that structures of complexity frequently involve hundreds of variables, hence the computerized version of formal logic, as offered in the Interpretive Structural Modeling (ISM) system, provides the essential capacity that is utterly lacking in the equations of physical science. The mathematics of formal logic embody directly the logic relations that are implied by “necessary conclusions", and the algorithm of ISM assures that the logic portrayals are consistent. If the mathematics of physics is relevant to complexity, it must be applied AFTER the logic has been found, portrayed, and interpreted.

For most people, mathematics is impenetrable, so a prose-graphics combination is used to enable the broad communication that is often required to resolve complexity cooperatively.

4. What has been discovered empirically about the necessary requirements of

language in order that it can portray complexity? Where? By whom? In what publications?

A **metalanguage** is required (ordinary prose being acceptable) to formulate the basic phrases that will be structured, while an **object language** (based in formal logic) is required to translate those formulations into symbolic expressions that are suitable for computer logic calculations.

The core mathematics of **analysis** was published in this book:

F. Harary, R. F. Norman, and D. Cartwright (1965): STRUCTURAL MODELS. AN INTRODUCTION TO THE THEORY OF DIRECTED GRAPHS, New York: Wiley.

The formulations necessary for synthesis of structural models were published in the following:

J. N. Warfield (1974): STRUCTURING COMPLEX SYSTEMS, Columbus: Battelle.

J. N. Warfield (1976): SOCIETAL SYSTEMS: Planning, Policy, and Complexity, New York: Wiley Interscience.

The **metalanguage** is used to generate the raw material, the mathematically-based **object language** is used for computer-assisted processing, and the **prose-graphics language** is used for human beings to interpret and learn about problematic situations.

6. What are the "Killer Assumptions" that undermine high-quality work pertaining to complexity?

So far, 17 Killer **Assumptions** have been found. It is expected that still more will be discovered. Several hundred thousand possible **combinations** of these 17 can be formed, any one of which can constitute a Killer **Framework** in someone's mind, and any Killer Framework may be effective in assuring that complexity cannot be resolved.

The Killer Assumptions found to date are distributed among these six categories: Assumptions about:

- *Complexity*
- *Evidence*
- *High-Level Executives and Their Decisions*
- *Learning*
- *Group Processes*
- *Infrastructure*

6. Who are the "Thought Leaders" from the past that have contributed to showing how to overcome these Killer Assumptions? In what publications do their ideas appear? How have their ideas been tested in problematic situations?

The Thought Leaders from the past who have been identified to date are:

- Peter Abelard
- Aristotle
- W. R. Ashby
- G. Boole
- K. Boulding
- A. De Morgan
- J. Dewey (minimal)
- M. Foucault
- G. Galelel
- J. W. Gibbs
- F. A. von Hayek
- D. Hilbert
- A. Lavoisier
- H. Lasswell
- G. Leibniz
- F. S. C. Northrop
- C. S. Peirce
- A. Pope
- G. Vickers
- A. N. Whitehead

Their publications appear in most academic libraries. For a 90-page partial bibliography, see "The IASIS File"., which is located at this web site:
http://www.statewave.com/tiers_1_4/BIBWARF.htm
More bibliographical information can be found at.
http://www.gmu.edu/departments/t-iasis

Their ideas have been tested repeatedly in Interactive Management Workshops, in which the Interactive Management processes incorporate many of the ideas set forth by these Thought Leaders.

7. From what areas of study do the Thought Leaders arise?

The areas of study of these Thought Leaders (all deceased) were:

- Formal Logic (Analytic Philosophy)
- Cybernetics
- Systems Science
- Speculative Philosophy
- History of Systems of Thought
- Physics
- Physical Chemistry
- Statistical Mechanics
- Vector Analysis
- Mathematics
- Law and Chemistry
- Political Science
- Law, Mathematics, and Librarianship
- Philosophy
- Chemistry, Mathematics, Philosophy, Logic, and Precision Measurements
- Poetry
- High-Level Administration in Government and Industry
- Mathematics and Philosophy
- Economics

8. Why might one correctly conclude that complexity cannot be adequately dealt with by (a) individuals?, (b) groups?, (c) organizations? What are the implications for management of complexity in organizations?

(a) Individuals lack the breadth of experience. They are limited in the span of immediate recall, which means that they cannot study collectives of concepts to arrive at logic relationships among them through individual effort, unsupported by other avenues. (b) Groups are known to suffer from groupthink, clanthink, and spreadthink: pathologies which have been demonstrated to bring about very poor outcomes. (c) Organizations engender structural incompetence by an overabundance of regulations, a lack of vertical linguistic coherence, and inadequate infrastructure for working with complexity.

Management of complexity in an organization requires a system that annuls or compensates for the pathologies of individuals, groups, and the organization. Morever the organization should provide the infrastructure that is required to work with complexity.

9. What are the six types of relationships? What is meant by the *Discretionary Model Management Parameters?* How can using them help avoid underconceptualizations in science and in applications?

The six types of relationships are: Influence, Definitive, Comparitive, Spatial, Temporal, and Mathematical. Relationships can belong to more than one type.

The Model Management Parameters consist of all of the ideas represented in the following definitions which should be applied in order to specify a model. Notably most of these parameters are habitually ignored in developing models.

MODEL MANAGEMENT

DEFINITIONS

SITUATION. That system (something which a human being proposes to study for the purpose of exploring changes within it) of current interest, along with the environment of that system.

DIMENSIONAL DESCRIPTION OF A SYSTEM. A set of dimensions and selections from dimensions, such that at least one selection from each dimension is represented in the description of the system.

DIMENSION (CHARACTERISTIC) OF A SYSTEM. A monadic category germane to the system, without which the system cannot be adequately described.

DIMENSIONALITY OF A SYSTEM. The number N of dimensions which the human detects and names in modeling a system, which meets the ongoing test of completeness, by noting whether the Law of Requisite Variety is satisfied in the operations that involve the system.

SPECIFICS. Components of a dimension. The components could be, e.g., problems or options. If they are options, a subset might be chosen for purposes of a particular design.

SELECTED SPECIFIC. A specific that a human chooses as part of the dimensional description of a system. Choice is available when a system is being designed, otherwise when an observable system is being defined the choice is only linguistic and not otherwise arbitrary.

NAME (DOMAIN) OF A DIMENSION. The name assigned to the total set of specifics for a particular dimension, i. e., to the set of components of that dimension.

RELATIONAL DESCRIPTION OF A SYSTEM. A two-part package consisting of
(a) Linguistic Part. A set of relationships required to describe mutual conditions involving two or more dimensions, (b) Mathematical Part. A set of mutual conditions (dyadic or higher, i. e., involving two or more dimensions) specified symbolically in a recognized mathematical area.

CARTESIAN SPACE OF A SYSTEM. The set of ordered N-TUPLES of all specifics of the system, where N is the number of dimensions of the system, i.e., the system's dimensionality.

FIELD DESCRIPTION OF A SYSTEM. An array in which each dimension appears as a column heading, followed by the set of all specifics of that dimension, each being written with a bullet preceding it for syntactical clarity.

PROFILE DESCRIPTION OF A SYSTEM. A graphical construction that begins with the Field Description of the System, and which contains a TIE LINE, and for which all selected specifics are directly connected to the TIE LINE by SELECTION LINES running from the bullets of the selected specifics to the TIE LINE. Typically a profile is made to specify a particular design alternative, in which the dimensions consist of sets of options. With an appropriate computer, the selected components can be distinguished by choice of font, instead of using selection lines.

POWER MAP (LATTICE-BASED-MAP DESCRIPTION OF A SYSTEM). A hierarchical structure beginning at the bottom (level Zero) with the Φ-element (representing the empty set), and continuing vertically, based on an inclusion relationship, such that the ith level contains a number of members equal to the number of combinations of n things taken i at a time; each member containing i dimensions, and such that every possible combination of the N dimensions taken i at a time is represented in the ith level.

Thus the first level contains N members, each being one dimension of the system; the second level contains N(N-1)/2 members, each being a unique pair of system dimensions; etc., while the top level contains one member, that being the total set of dimensions of the system.

MONADIC. Containing only one element, which is selected to be unique in its type in the situation under study

DYADIC. Containing exactly two elements, each being monadic.

TRIADIC.. Containing exactly three elements, each being monadic.

n-ADIC. Containing exactly n elements, each being monadic.

MODEL GRAPH. A bipartite graph with two sets (two types) of vertices and one set of lines (edges), each line (edge) connecting one type of vertex to the other type of vertex. One set of vertices, called "nodes", corresponds to a model's relationships. The other set of vertices, called "knots", corresponds to the model's variables (dimensions). (Friedman's formulation)

If these Model Management ideas are articulated, it becomes possible to subject the model to scrutiny and possible improvement, but if all that is presented is the model itself, little help can be provided. Effective Model Management will be ongoing, and will keep the model updated for maximum utility.

10. **What schools of thought promise to continue to obscure the nature of complexity, by introducing popular (but wrongly-conceived) ideas about complexity into business schools and other academic arenas?**

The Indifference School, the Systems Dynamics School, the Chaos Theory School, and the Adaptive Systems School. For details see: "Five Schools of Thought About Complexity: Implications for Design and Process Science", Tanik, M. M., et al (Eds.), Integrated Design and Process Technology, IDPT- Vol 2, 1996. (Proc. Society for Design and Process Science, Austin, TX, 389-394. See also C. François (1998): Encyclopedia of Systems and Cybernetics, Munich: Naur.

11. **What is the Mathematics of Structure? Why is that little-known branch of mathematics the appropriate foundation for developing interpretive models? Why can't people use that directly, instead of relying on software assistance? How does this mathematics ensure consistency in structuring problematic situations?**

The Mathematics of Structure consists of Boolean algebra, sets, binary relations, binary matrices, binary matrix models, digraphs, digraph maps, digraph models, and partition mathematics, all integrated into a high-utility package for structuring conceptual information.

People cannot use it directly because the human mind is limited in its processing capability, and the necessary human interaction has to be designed for effectiveness and efficiency, taking into account appropriate infrastructural requirements. The mathematics assures consistency (but not correctness) by focusing only on transitive relationships and enforcing Harary's Boolean matrix equation $M^2 = M$ as a condition of a reachability matrix that is convertible to a digraph-like structure, in which the interpretation has been entered onto the graphic (as in e-g., problematiques, enhancement structures, DELTA charts, etc.).

12. **What software packages are available to apply in structuring complexity?**

The Cogniscope™ of CWA, Ltd; Synergistic Solution™ of DeSyMa, Ltd; the Tlatocan of IT'ESM, Campus Monterrey; the GMU ISM for Windows package; and the older DOS-Based GMU ISM software which has been made available for free downloading, along with a User's Guide at this web address: http://www.gmu.edu/departments/t-iasis.

13. **In working with complexity, how are the roles of individuals, groups, and organizations identified and allocated, in order to overcome the behavioral limitations associated with each?**

Roles are assigned to individuals or to groups or to the organization, according to which is most likely to be capable and effective in each action component. These role assignments are made in conjunction with the Work Program of Complexity, to be described later in this document; and are further illuminated in John N. Warfield and A. Roxana Cárdenas (1994), A Handbook of Interactive Management, Ames, IA: The Iowa State University Press.

Part 2. Science of Complexity

1. What can be learned from the Thought Leaders about the meaning of complexity"?

The Nature of Complexity. In his famous paper published in 1878, titled "How to Make our Ideas Clear", Charles Sanders Peirce talked about false distinctions that are sometimes made in discussing beliefs. He wrote the following:

"One singular deception of this sort, 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.

After reflecting on this quotation, I believe that complexity belongs in the same category with other human feelings (sensations) such as dismay, horror, love, hate, and confusion. That is, it is a feeling that is aroused when people cannot comprehend the object of interest to them. It is the composite effect of perplexity which, acting within an individual, is shared by the larger relevant society.

Those who think that complexity is a property of what is being observed have to face up to the challenge of trying to find, in a multitude of observable systems, an attribute that is shared across all the many different types of observable systems. Even if that could be done, the question would remain about how they could do this for those systems that are merely being thought about, such as systems to be designed, which do not even have any observable character. And then they would also have to explain why some observable systems seem to be understood by some people, but not by others. Finally, it is worth noting that when people propose some measurement of complexity, inevitably it will involves something that people have thought about or perceived, as opposed to measuring something like the color blue, for example, which can be subjected to physical instrumentation.

2. Is a science of complexity possible? What must a science of complexity entail? Why?

Yes, a science of complexity is possible, and is partly completed now. Although nowadays, it seems that almost anything can be called "a science" without questions being raised, it is still true that anything called a science ought to meet the classical standards, set forth in response to Question 4 below.

3. Why should present-day practitioners become knowledgeable about the Science of Complexity: Why not just draw on it, as practitioners do in other areas of engineering, for example? (Hint: what or who are "fashion accessories for top management", according to M. C. Jackson?)

It is well-established today that top-level managers in organizations draw on “management gurus" who promote points of view that do not meet scientific standards. M. C. Jackson calls some of these gurus “fashion accessories for top management". Some of the gurus have been described as Witch Doctors in a popular book by two Editors of the journal *The Economist.* Practitioners who believe that a science of complexity underpins a management practice need to be armed to defend and even promote their views inside the organization, as a way of competing with the gurus.

4. What minimum set of components should a science contain in order to deserve to be called a science? Who monitors, assesses, and "blows the whistle on" the current propensity to call everything a science that is taught about high-tech subject matter and modern management (e.g., "computer science", "management science")?

Based on the historical concept, a science should involve the following:

• A constructive chronology of its evolution
• Laws, with explanations of their origins
• Empirical evidence to support the findings
• Archival reports that show results in detail
• Primitive definitions (often equivalent to key assumptions)
• A "community of scholars" (terminology from C. S. Peirce) who not only teach and test the science, but who also constantly search for shortcomings and try to correct them. In effect they offer stewardship to the science.

At present there seems to be a shortage of the "communities ".

5. How does the Science of Complexity meet the minimum-components requirement?

The chronological requirements are met by showing the evolution of thought about thought, from the early days of Aristotle to the twentieth century. The book by L. M. Bochenski called A History of Formal Logic shows much of the evolution. The book by M. Foucault titled The Archaeology of Knowledge describes the shortcomings that need to be corrected. The paper "Twenty Laws of Complexity: Science Applicable in Organizations" in *Systems Research and Behavioral Science* (1999) gives the Laws and shows their origins. Empirical evidence is offered in several papers, such as "The Magical Number Three, Plus or Minus Zero" (1988) and "Spreadthink: Explaining Ineffective Groups" (1995), by John N. Warfield; the former appearing in the journal Cybernetics and Systems and the latter in the journal Systems Research. These articles form part of the archival products, and other parts of this can be found on the web site: http://www.gmu.edu/departments/t-iasis. The community of scholars is small, but is recognizable. Some members are identified along with their work in an appendix to the paper "Twenty Laws of Complexity" mentioned above. Still others are identified in Appendix 5 in the book by J. N. Warfield and A. R. Cárdenas (1994), titled A Handbook of Interactive Management, Ames, IA: The Iowa State University Press.

6. What are the Seven Ways to Portray Complexity that are known so far? How can such portrayals be generated?

- 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)

These portrayals can be generated with the help of the Interactive Management system.

7. What do these seven ways have in common? How do they differ?

The components of the seven portrayals can all be generated using the Interactive Management (IM) system. Two of the portrayals require special attention. The Element-Relation diagrams do not correspond to digraphs. The DELTA Charts may have more than one element type. The other five fit the standard pattern of IM work, but some of them are best portrayed in the field type of representation, while others are best portrayed in the structurally-isomorphic digraph mode.

Many practitioners do not understand the commonality that is present. They do not realize that the ISM computer-assistance process enables the structures to be developed with machine help. As a result, they tend to let individuals develop the structures manually, instead of getting the benefits of group activity, with all of the valuable by-products that accrue from that.

8. What are the 20 Laws of Complexity? What is the taxonomy of these Laws?

The 20 Laws are published (1999) in *Systems Research and Behavioral Science.* The Laws fall into three categories: Behavioral, Media-Related, and Mathematics-Based.

9. What are the five metrics (indexes) of complexity? How can the values be determined? What are the "reference values" (values at the boundary between normal situations and the problematic situations involving complexity)? How are the reference values justified?

The metrics are:

The **Miller Index**, relating to the quantity of information involved
The **De Morgan Index**, relating to the number of distinct binary relationships involved
The **Spreadthink Index**, relating to the differences of opinion among members of an informed group
The **Situational Complexity Index**, formed as the product of the first three mentioned
The **Aristotle Index**, relating to the number of syllogisms found in the problematique

A reference value of 1 can be defined for each of these, with values below 1 indicating absence of complexity, and values above 1 indicating presence of complexity. In practice, values are inevitably significantly above 1 for all of these indexes. The use of 1 as the boundary is justified by research showing the limitations of human minds, arising from the behavioral pathologies.

10 . What data support the significance and measurement of the five indexes? What organizational managements presently acknowledge them, and apply them to help determine when to give preeminence to complexity as a driver of organizational practice and an essential definer of organizational infrastructure?

Numerous applications at the Ford Motor Company have generated data on the indexes. A thorough treatment of four of them appears in this paper by a member of the Ford Scientific Research Laboratories:

Scott M. Staley (1995): "Complexity Measurements of Systems Design", in <u>Integrated Design</u>

and Process Technology (A. Ertas, C. V. Ramamoorthy, M. M. Tanik, L. I. Esat, F. Veniali, and Taleb-Bendiab, Editors), IDPT-Volume 1, Austin, Texas, 153-161.

No top-level managements are known that presently acknowledge them..

11. **What applications of the Science of Complexity have been made? Where? To what problematic situations? By whom? With what results?**

Numerous successful applications have been described in publications. Among the publications that identify many of them are:

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

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

12. **What infrastructure is required to enable complexity to be resolved?**

The best results are obtained if the following infrastructure is provided in an organization:

A **situation room** dedicated to applications of the science of complexity through the practice of Interactive Management (such a room is thoroughly described in various publications). Several organizations have incorporated such a room.

A **small IM staff**, expert in the application of Interactive Management. Several organizations have such a staff.

Organizational budgets that support group work on a wide variety of issues. Few organizations have such a budget line.

Training programs that support the work that goes on.

A **corporate observatorium** that is maintained and which documents the products of the application of the science in a highly-visible, cognitively-respectable, and easily accessible location. See J. N. Warfield (1996), "The Corporate Observatorium: 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.

Part 3. Applications of the Science of Complexity

1. By what process is complexity resolvable?

Complexity is resolved by following the four work components in the Work Program of Complexity, being guided by the description of Interactive Management as an **implementing** system.

2. What are the four work components of The Work Program of Complexity?

Description
Diagnosis
Design
Implementation

3. What are the four behavioral components of the Behavioral Allocation Menu?

Behavioral Process
Individual Behavior
Group Behavior
Organizational Behavior (induced by membership) in an organization.

4. What is the purpose of the Behavior-Outcomes Matrix?

The purpose is to show how various findings relate to the 16 possible combinations of elements from the Work Program of Complexity with elements from the Behavioral Allocation Menu. For example, which of the 20 Laws of Complexity relate to this pair:

(Description, Individual Behavior)?

5. What is meant by "pathologies"? ... by "behavioral pathologies"? .... by "individual behavioral pathologies"? .... by "group behavioral pathologies"? .... by "organizational behavioral pathologies"? How do these pathologies inform the allocations of work when The Work Program of Complexity is underway?

According to my Webster: a pathology can mean "all the conditions, processes, or results of a particular disease".

A behavioral pathology is anything that affects the ability of an 'individual to perform well, singly or in a group. An individual behavioral pathology of interest in connection with complexity is that described by G. A. Miller, later by H. A. Simon, and still later by J. N. Warfield. That is the inability of an individual mind to process more than about seven ideas or, as Warfield described the using up of the number 7 by 3 ideas and the set of 4 possible interacting schemes, i.e., (ab), (ac), (bc) and (abc), which represent the distinct interaction modes of the three elements a, b, and c. Then when the number of elements goes to 4, we have 11 interaction modes, bringing the total sphere of investigation to 15; a number well above Miller's "magical number seven".

Group pathologies include Groupthink, Clanthink, Spreadthink, and Underconceptualization. Each of these pathologies has been described in publications, and some case studies are available in great detail to illustrate them in situations in government and industry.

Organizational pathologies are those induced on both individuals and groups by management structures, rules and regulations, and organizational politics. The most prominent pathology is called "structural mcompetence".

The allocation of behavior is carried out according to which behavioral component has the best qualifications to carry out the relevant work component of the Work Program of Complexity. Throughout this allocation the Process component of the Behavioral Menu comes from the carefully designed Interactive Management system, with a White Paper and a Workshop Plan constructed each time to augment the IM system with the specifics of the particular situation.

6. For each component of the Work Program of Complexity, which behavioral component is most appropriate as the actor? Why?

Description: best done by groups (8 to 15), because each member has distinctive knowledge that can be aggregated with the help of Interactive Management

Diagnosis: best done by an individual who is experienced in using the diagnostic aides developed for interpreting the structures produced in Interactive Management Workshops, especially in interpreting the Problematique; provided the individual then shares the diagnosis in an Interpretation Session with the group that produced the results, both to check out the interpretation, and to make any needed amendments

Design: best done by groups (8 to 15), because each member has distinctive knowledge that can be aggregated, with the help of Interactive Management

Implementation: best done by the organization (whatever components that are required), following the Interpretation Session with the group that produced the results, both to check out the interpretation, and to make any needed amendments.

The allocation of behavior is carried out according to which behavioral component has the best qualifications to carry out the relevant component of the Work Program of Complexity. Throughout this allocation the Process component of the Behavioral Menu comes from the carefully designed Interactive Management system, with a White Paper and a Workshop Plan being constructed each time to augment the IM system with the specifics of the particular situation.

7. For each component of the Work Program of Complexity, what products can be constructed that will illuminate that component? How should these products be constructed?

All products are constructed as described in the Handbook of Interactive Management. These are the products that are most relevant to particular components of the Work Program of Complexity:

Description: A Type 1 problematique, a problems field, an attributes field, with computation of a Type 2 (categories) problematique

Diagnosis: An analysis and classification of problems from the Type 1 problematique, based on its structural features; computation of indexes of complexity for comparison with earlier studies, and a comparison of the categories problematique with organizational components to assess who might be doing what.

Design: An options field with one category for each category in the problems field, at least two independently-developed options profiles by subgroups, a final options profile selection done in plenary session; and a DELTA Chart showing what tasks will be performed in order to implement the design and who will perform those tasks.

Implementation: A Work Breakdown Notebook, keyed to the DELTA Chart, augmenting the information shown on the chart; and large displays of products of the IM work, along with any essential aids to interpretation, the displays and interpretive aids being located in the corporate observatorium for learning, amendment, and archival purposes.

8. For each component of the Work Program of Complexity, what purpose is served by each of the products that can be constructed for that component?

For the **Description:** The problematique shows how key problems are interrelated. The problems field shows the named categories in which the problems lie, any interdependency among the problems tied to the problem categories (producing clusters of categories), and the sequence in which design decisions will be made, taking account of the interdependencies.

The attributes field describes the attributes of the system to be designed, along with the categories in which those attributes can be placed, providing information to show what parts of the organization may be involved with which attributes.

For the **Diagnosis:** The analysis shows which problems and or problem categories appear to be critical for immediate action, which problem groups need to be packaged collectively for action, which problems require review based on what was said about them during the Description work, and which problems do not seem to require immediate action because more fundamental problems are sustaining their problematic character. The analysis also shows an overview of the problematic situation, yielding insights that should be helpful for ongoing management activity.

For the **Design:** The Options Field shows the wide variety of possible options and the categories in which those options lie (these being the same categories as found earlier in the Problems Field).

Each Options Profile corresponds to a particular Design Alternative, being determined in the light of all the available products from the use of IM, and the final choice made provides the pattern overview for the planned system design that will resolve the complexity involved 'in the problematic situation.

For the **Implementation:** The DELTA Chart shows the planned sequence of activities, events, and decisions, along with who will be carrying out those activities and making those decisions. The Work Breakdown Notebook provides the necessary detail to accompany each component of the DELTA Chart including time required, staff required, cost estimates, etc. The Corporate Observatorium makes the full panoply of information available across organizational boundaries.

9. For each component of the Work Program of Complexity, why cannot the products be developed using normal processes?

The complexity involved in the **Description and Design** activities, as measured by the various indexes of complexity, is far too high to let normal processes work effectively in meeting cognitive requirements of the situation, and group work is far too susceptible to the group pathologies to allow normal processes to be used.

The **Diagnosis** depends heavily on an ability to interpret structural models, which is not an ability that is available from persons who work regularly with normal processes.

The **Implementation** involves a deeper, more profound, knowledge of the problematic situation than can be provided by normal processes, and may require that this knowledge be widely available across the organizational boundaries, both for guidance and for possible amendment of any misunderstandings that might have been incorporated in the structures and interpretations produced

10. **For the <u>Design</u> component of the Work Program of Complexity, what process requirements should be met in order to communicate the various alternative designs to others who were not involved in developing them?**

The processes used should support the development of the structures described in responding to Question 8 above. The processes should also benefit from the infrastructure recommended to make the necessary portrayals of the complexity.

People need training in order to know how to read and interpret the structures produced, both to learn what they show, and to help them envisage any possible amendments that may be required to improve the implementation.

11. **For the <u>Design</u> component of the Work Program of Complexity, what process requirements should be met in order to explain, to other people who were not involved in making the choice, why a particular alternative design was chosen for implementation?**

A record should be kept of the discussions that went on in the plenary session where the several altematives were compared. Among the records to be displayed later are the similarities and differences among the alternative designs that were considered

12. **What is a shared linguistic domain? Why must it be developed during the progress of The Work Program of Complexity? Why is it more than just a common vocabulary? Why can it legitimately be called a byproduct of the work?**

A shared linguistic domain means that the members of a group of people have each acquired sufficient commonality in their language that they can discuss a problematic situation knowingly and be effective in communicating their ideas. Normally such a domain does not exist at the beginning of the application of Interactive Management, and it is produced as a byproduct of the work because of the combination of the "clarification " session that always accompanies the application of the Nominal Group Technique (NGT), and the discussions that go on in applying Interpretive Structural Modeling (ISM) to examine the interrelationships among the elements being structured and the interpretation sessions that follow.

13. **Why do practitioners need to learn The Infrastructure of Science in order to become powerful in applying The Science of Complexity?**

Even with the carefully developed procedural algorithms that have been described in the *Handbook of Interactive Management,* issues always arise in considering whether to apply IM or how to apply it. Invariably, these issues can be resolved by recourse to the Science of Complexity.

Part 4. Site of Applications (the Organization)

1. Why do organizations exist?

Organizations exist to do things that individuals, acting alone, cannot do. When the benefit of having multiple actors is chosen, one must accept the accompanying disadvantage of escalating the burden of communication among members of the organization. When the organization must cope with complexity, the means of communication must be compatible with the demands of complexity. Hence it is well to learn what those demands are.

2. What pathologies do large organizations exhibit? What are some of the undesirable consequences of these pathologies? What is meant by "structural incompetence"?

In his study of bureaucracies at the Rand Corporation several decades ago (as reported in the book: Anthony Downs: *Inside Bureaucracy)* the author showed that behavior in bureaucracies is predictable, being governed by certain laws that seem to be inherent in large organizational behavior. These behaviors have little to do with the tasks at hand, and have a lot to do with personal protection and protection of the organization as a whole. Since many of these behaviors mitigate against effective individual performance, the concept of **"structural incompetence"** was invented by some federal program managers as a blanket terminology for the pathology that the organization imposes upon the individual. Inevitably this pathology undermines the original purpose of the organization, and has even produced the "whistle blower" as an innovative means of helping to provide a correctional bulwark for punishing extremely bad organizational behavior.

3. When is modeling by groups essential to attaining quality in representation of complexity?

Modeling by groups is essential any time when (a) the consequences of acting on knowledge of one individual are potentially severe and (b) there is little reason to expect that the one individual has sufficient knowledge and experience to select an appropriate course of action.

The proven concept of Spreadthink is very informative in this regard, revealing that people involved in problematic situations always have different views of what is important, showing us that no one's point of view is likely to be adequate to resolve the complexity. But pooling of the group's knowledge has a high probability of succeeding, if properly integrated.. Yet modeling by groups may be ineffective, if a process is used that is inconsistent with the demands of complexity.

For more details, see: Warfield, J. N. (1995), "Spreadthink:. Explaining Ineffective Groups", Systems Research 12(l), 5-14.

4. **What are the types of models from which informed choices can be made? What types of models are appropriate for each of the steps in the Work Program of Complexity?**

Models should meet the requirement for the best combination of insight and simplicity. This typically implies that **structural** models should be constructed; and that people should be trained in how to develop, portray, read, and interpret such models. Here are types appropriate for the steps in the Work Program of Complexity:

Description: Problematique, Problem Field, Attributes Field
Diagnosis: Structural Diagnostics
Design: Options Field, Options Profiles, DELTA Charts
Implementation: Visual Displays with Interpretation Aids.

5. What empirical evidence indicates that engineers and managers cannot read and interpret interpretive structural models? Should this discrepancy be corrected? Why?

Professor George T. Perino of the Defense Systems Management College, Fort Belvoir, VA, provided questionnaires to several hundred certified program managers in the Department of Defense (almost all of these were in the RSTJ type on the Briggs-Myers rating system). One questionnaire presented a part of the John Deere pump manufacturing problematique described in *A Science of Generic Design* (page 395). It was explained there that the pump situation involved multiple influences **(not just one cause!!)** which, upon review of the problematique, were identified; and the situation was then corrected. Many of the program managers were mechanical engineers, who already believed they knew quite a bit about pumps and did not need to rely on the problematique for more information.

One of the questionnaires was a "forced-response" type, where each question offered four possible responses. Each question involved reading and interpreting the partial problematique. With this type of questionnaire, the expected correctness score for a random respondent (i. e., one answering by choosing a number from 1 to 4 at random) would be 25%.

The respondents average score was about 19%, or worse than a random respondent.

Some possible explanations for this poor performance are:

a) The respondents did not know how to "read" the problematique.
b) The respondents answered based on their previous experience with pumps, disregarding what the problematique showed.
c) The respondents thought the problematique was like a "PERT" chart or other graphic with which they had past experience, and they could interpret it as a temporal flow.
d) Some or all of the above.

In any case, the conclusion was what experience had previously suggested: namely that because people receive little or no instruction in how to read structural graphics, an intuitive approach is not only wrong but dangerous as an approach to decision-making. A further belief is that the great discrepancy between the amount of time spent in teaching prose (i.e., instruction in English from kindergarten through college) greatly favors prose as a means of communication at the expense of the combination of prose and graphics. Administrative action is required to correct this situation.

A further difficulty is that, through common practice, structural graphics has become in itself an intuitive means of description and, as commonly used by engineers and others, lacks the rigorous definition required to make accurate reading of prose-graphics combinations possible. This is a serious shortcoming in education which one hopes can ultimately be remedied One first step toward that end is the production of the "Prose-Graphics Glossary of Complexity", for which a first draft is available, and which will receive ongoing attention in order to arrive at a suitable first edition.

6. What prevents engineers and managers from reading and interpreting interpretive structural models? How hard would it be to overcome these inhibitors?

They have developed many **bad** habits in relation to structural models, thinking that they can communicate effectively with them in spite of the inadequate definitions they have internalized. One of these is to use symbols on the graphic (e. g., arrows), the meaning of which is left to the imagination of each individual observer. I have proposed that a structural graphic must be uniquely translatable into prose, as a condition for its acceptance as a vehicle for communication. This condition is almost always ignored by people who create graphics. Moreover the graphics "gurus” do nothing to correct the deficiency. Instead they promote graphics types that have been placed in use which inevitably suffer from inadequate definition. A further difficulty is that most software programs that purport to support construction of structural graphics suffer from significant deficiencies.

In principle it is easy to overcome these inhibitors, but the system that could provide a solution is so insensitive to the problems and indifferent to them, that nothing is likely to happen in the ftiture unless some professional society with clout rises up and demands action.

7. What is meant by "The Corporate Observatorium"? From what Thought Leader did this concept arise? Through what means did the thought leader arrive at the concept? What related concepts are needed to make this concept practical as a means of overcoming vertical incoherence in organizations?

The concept of observatorium is familiar to those who have seen a small version of the sky, usually in a domed building. The Corporate Observatorium is a piece of real estate dedicated to a learning process, where products of high-quality work on complexity are located in highly-visible formats, along with such learning assists as recordings, video tapes, real people offering explanations and responding to questions, etc.

The original idea came from the work of Harold Lasswell, who studied policy formation extensively and concluded that the means of providing support to policy designers were very unsatisfactory. Lasswell also urged that "decision seminar rooms " be built, which are equivalent to the highly-recommended concept of "situation room" for conducting Interactive Management Workshops.

For more information, these references can be consulted.

Warfield, J. N. (1996), " The Corporate Observatorium: Sustaining Management Communication and Continuity in an Age of Complexity", in Tanik, M. M. et al (Eds.), *Integrated Design and Process Technology, Vol. 2* (Proc. Society for Design and Process Science), Austin, Tx, 169-172.

Warfield, J N. (1994), *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.

Lasswell, Harold (1971), *A Pre- View of the Policy Sciences*, New York: American Elsevier.

8. What is Interactive Management (IM)? Why was it developed? How has it been used in Ford Motor Company?

As defined in the book: J. N. Warfield and A. R. Cardenas *(1994), A Handbook of Interactive Management,* IM is "a system of management invented explicitly to apply to the management of complexity".

Ford Motor Company is one of numerous users. It has been a frequent user, probably doing more IM Workshops than any large corporation. It has been used on a variety of projects, mostly relating to system design.

Ford has a program where its employees can make contributions to their communities as part of their work assignments for Ford. Roy Smith, a Ford employee in the United Kingdom, and a planner and facilitator of in-house projects at Ford, has learned to use IM effectively, and has conducted several workshops for community groups in the U. K., gaining high praise from them for his efforts.

IM was introduced in Ford as a result of the efforts of Dr. Scott M. Staley of the Ford Research Laboratories. Through his efforts, several hundred Ford employees have taken part in IM Workshops, and several Ford employees have learned how to serve as staff of such workshops. Ford has developed and put in place a situation room to carry out IM Workshops.

9. How has IM been used in other organizations?

Chapter 1 of the book: J. N. Warfield and A. R Cárdenas (1994), *A Handbook of Interactive Management*, tabulates 115 examples of its use in a variety of organizations through the year 1994. Many other applications have taken place since that time, making it almost impossible to keep a complete record of the projects.

10. What generalized conclusions have been drawn about the demonstrated utility of IM in a wide variety of applications, with a wide variety of organizations?

Several hundred IM Workshops have taken place since it was introduced. No complaints about the products have ever been recorded when the recommended processes have been followed. Numerous evidences of high levels of satisfaction have been noted, and several awards have been given as a result of the use of IM, some to practitioners and some to organizations.

Hence it is concluded that IM, when applied, as "a system of management invented explicitly to apply to the management of complexity", has been quite successful, at least in the eyes of the user organizations, in fulfi1ling the stated purpose.

Some organizations, e.g., The Americans for Indian Opportunity, have said that they had tried virtually all the other processes promoted by gurus, and found them unsatisfactory but, after trying Interactive Management, they concluded that it had all the features they had been seeking.

The government of the Mexican State of Guanajuato created an organization with over 250 members specifically to take advantage of the information developed in running more than a hundred IM workshops with various socioeconomic and political sectors in that State.

Several small consulting firms are based in the use of Interactive Management, and a few universities provide education in this field.

Interactive Management is one of the few (and possibly **the only** complexity-oriented) systems that meets all of these requirements:

a) **Full disclosure**. Its explanation is widely available in the literature (not described only in terms of metaphors)

b) **Replicability of Process**. The explanation is in significant depth, so that replication is possible, which permits comparisons to establish credibility.

c) **Specializing in Resolving Complexity**. It is intended only for resolving complexity in organizations (although some find ISM helpful in their individual projects).

d) **Sizeable Record of Adding Value in Applications**. It has been applied in many

organizations, and has added significant value whenever it has been used.

e) **Founded in Science.** It is founded in science, the science being thoroughly described, its origins being identified, and the connections with it being demonstrated.

11. How has the use of IM contributed to an understanding of the essential nature of complexity?

There is only one system of formal logic that has drawn more than casual interest among a broad scientific community, that being the so-called "Western logic", associated with such scholars as Gottfried Leibniz, Augustus De Morgan, George Boole, and Charles Sanders Peirce.

That being the case, with the results being well-defined and now pragmatically useful, IM offers a unique support system for developing an understanding of what was thought to be complex; and for arriving at a widely-understood plan of action for resolving the complexity. Because of this uniqueness, and because there is little that is much more basic than thought as a means of resolving complexity, IM provides a basis for structuring collective knowledge that is more basic than products of other systems intended to support design and decision practices.

From the base of knowledge that it provides, not to mention the opportunity for widespread review and learning, IM offers a sound springboard for the application of other, better known, formalisms such as quantitative formulae from physics or other sciences.

12. How does the application of Interactive Management lead to and enable the numerical computation of the Indexes of Complexity? How do the numerical values of these Indexes of Complexity provide credibility to the underlying Science of Complexity? Who has tried to invalidate these Indexes? With what results?

The products of group work aimed at resolving complexity enable data to be accumulated that relate to the complexity involved This means that one does not need to do artificial experiments just to collect data, but rather can just draw on the natural outcomes of productive group work as the source of data. These data can then be introduced into the definitions of the Indexes to enable computation of the numerical values.

Since comparable Indexes can be computed for different projects, it begins to be possible to see just how much complexity is involved, and how far the Index values depart from the definition of "normal situations" to which most common algorithms apply. It is also possible to make numerical comparisons of relative values among different situations, which gradually helps management build an intuitive understanding of just how dangerous it is to manage projects that involve complexity, applying only the normal commonly-understood tools.

There is no knowledge available to show that anyone has tried to invalidate these Indexes. Hence there are no results. It is known that none of the other Schools of Thought about complexity seem to lack the capacity to arrive at suitable indexes and, as might be imagined, are uninformed about those applying to IM.

(For a reporter's article on that situation, see the New York Times article by George Johnson: on "Researchers on Complexity Ponder What It's All About ", Tuesday, May 6, 1997, beginning on page C1.)

13. **What does Fertig's research show about using boxed prose in combined prose-graphics representations? How do commonly-used engineering graphics violate her findings? What are the consequences of the use of informal engineering structural graphics?**

In her doctoral dissertation at the University of Virginia (1974), Janet Fertig studied the question of how much prose should appear in an isolated form (e. g., in a box on a structural graphic) to enable optimum understanding. Her conclusion was that about 8 words formed the optimum size. (If just one or two words were used, not enough information was presented to make a valid assessment. If, say, 20 were used, too many interpretations were cued by the extensive prose.)

These findings are notable in terms of evaluating long-standing engineering practice, in which:

a) Typically one or two words are used in each box of a box-arrow type of graphic.

b) Practitioners are seemingly totally insensitive to the critical importance of adequate communication (a matter noticed also by the authors of The Witch Doctors).

c) Practitioners seemingly don't comprehend that the capability of reading and interpreting an entire structural graphic can be severely undermined if just one or two of the prose components is misinterpreted, imagining perhaps that if the person creating the graphic understands it, anyone looking at it will likewise understand it.

d) The space requirements for communication fall victim to the use of miniature media, used regardless of the communication needs: e.g., 8½ by 11 or A4 paper, or computer screens; instead of using wall-sized space to facilitate group vision and conversation about the content, interpretation, and quality of particular structural graphics they have produced.

14. **What is normally done in using Interactive Management to interpret structural models and test their quality?**

Diagnostic computations based on the created structures are made, and the elements contained on the structure are classified according to the amount and nature of their interactions with other elements. Persons experienced in reading the structural models prepare interpretation materials and present them to the group that developed the models, along with the results of the diagnostic computations. By this means, the group is provided with interpretations of their products, helping them to gain insight and overview, and providing an opportunity to make any amendments that might be uncovered. Moreover the presentation and interpretation of the diagnostic work gives insight into future work and priorities.

15. **What is meant by "vertical coherence" in organizations? What evidence exists that supports the Law of Vertical Incoherence? What are some reasons why vertical coherence is much to be desired? What is presently being done in your organization to help ensure that vertical coherence exists? How are these practices relevant to the Model Management Parameters and the Indexes of Complexity?**

Vertical coherence refers to the existence of visible communication means that cover the territory from one extreme in the organizational hierarchy to the other. As an example, in his work to redesign the U. S. Defense Acquisition System, Henry Alberts' groups identified 678 problems. These were placed into 20 categories. The categories were placed into 6 areas. If we call the lowest level in the hierarchy the Operational Level, the middle level the Tactical Level, and the top level the Strategic Level, we see that the existence of this 3-level structure provides a basis for vertical coherence in the organization. The Model Management Parameters help provide objective ways to assess the quality of a model, and the indexes of complexity help show that efforts to resolve the issue have not failed just because the people were incompetent; but rather that competent people require effective processes when working with situations that produce high values of complexity indexes.

16. **What strategy can be applied to help ensure vertical coherence in large organizations? Who is presently following this strategy? Is anything being done as part of normal practice to try to create vertical coherence in large organizations?**

If the 3-level structure is kept in mind and supported by high-quality, visible displays; people in the Strategic Level can see how decisions they make involving one or more of the 6 areas ripple through the organization into the two lower levels. People in the Operational Level can see how top management's decisions relate to their own day-to-day problems. And people in the Tactical Level can see how their work couples or decouples people in the two adjacent levels. All of this communicability is made possible if the Corporate Observatorium is in place, and if it is kept up to date as required The price paid for vertical coherence and maintainability of communication is the cost of providing the real estate required to show the vertical connections and to support the staff required to get and maintain the displays.

17. **What are the "Organizational Design Levels"?**

It is fairly common for organizations involved in product design to think of these levels: Component Level, Subsystem Level, System Level, Organizational Level. To these we would add three other Levels, these being the interface Levels among the other four Levels. If the interface Levels are not recognized, they will not be budgeted. Budgets drive activity.

18. **What is "The Alberts Pattern"? Why is the Alberts Pattern seen as a potential organizational template to help provide vertical coherence?**

In his work to lead the redesign of the U. S, Defense Acquisition System, Henry Alberts' groups identified 678 problems. These were placed into 20 categories. The categories were placed into 6 areas. If we call the lowest level in the hierarchy the Operational Level, the middle level the Tactical Level, and the top level the Strategic Level, we see that the existence of this 3-level structure provides the basis for vertical coherence in the organization. This 3-level pattern is called the "Alberts Pattern".

A similar pattern, called the Cárdenas-Rivas pattern, was discovered in Mexico, in which the lowest level contained over 250 design options. These were placed into 20 categories, and the latter were placed into 4 areas. The project involved redesign of the Systems Engineering curriculum in ITESM (sometimes called the "Monterrey Institute of Technology ").

Patterns of the type described can be developed with the support of the IM system For more details, see:

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, L. L. Esat, F. Veniali, and Taleb-Bendiab, Editors), IDPT-Vol. 1, Austin, TX, 111-116.

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

19. What changes in higher education should be considered to challenge complexity? What is required to make such changes? Who is presently considering such changes in higher education? What would be the impact of such changes on engineering and organizations?

The redesign of institutions of higher education along the lines indicated by the foregoing is described in detail in John N. Warfield (1996): "The Wandwaver Solution: Creating the Great University" This document is available on the Internet at:

http://www.gmu.edu/departments/t-iasis. The requirements for making such changes are described in the report.

Two organizations have shown some interest. These are The Ohio State University College of Education (Professor Larry Magliocca) and The Colorado School of Mines (Dr. Robert Knecht).

Organizations and engineering could be dramatically impacted by such changes, because they could revitalize communication and support the design of systems having broad scope from a scientific basis. Similar benefits could accrue to the social sciences which are heavily fragmented, and which present incoherent disciplinary images to students.

20. **How is the foregoing relevant to Organization "X"?**

This question, if it is to be answered, will be answered by individuals in Organization X, who have seen the impact of complexity, and who are able to connect what is said here with what is going on in their organization.