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Citation for published version (APA):
Gigch, van, J. P. (1979). A methodological comparison of the science, systems and metasystem paradigms. *International Journal of Man-Machine Studies*, *11*, 651-663.

Document status and date:
Published: 01/01/1979

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

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Download date: 23. Aug. 2022

Int. J. Man–Machine Studies (1979) **11**, 651–663

A methodological comparison of the science, systems and metasystem paradigms

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(Received 28 February 1978, and in revised form 9 March 1979)

1. Introduction

Several systems methodologies which exemplify three different paradigms are surveyed and compared. These methodologies illustrate the application of:

the science paradigm (section 3),
the systems paradigm (section 4) and
the metasystem paradigm (section 5).

Examples of methodologies which incorporate these paradigms are discussed under the following headings:

(a) description of field;
(b) nature of domain;
(c) problems to which suited;
(d) application of the paradigm;
(e) nature of solution (or "truth" obtained);
(f) criteria to evaluate "truth";
(g) proof and guarantor of "truth".

For purposes of this study, a *paradigm* is defined as a distinct way of thinking about problems, in the sense given to this concept by Kuhn (1962). A paradigm is usually "content" or "substance-free" in the sense that it applies to many problems in a domain regardless of their specific content. A *methodology* is a problem oriented procedure or approach which incorporates a particular paradigm.

The intent is to show the characteristics of various methodologies presently available and to establish the requirements by which they may be evaluated.

2. Limitations

This paper refrains from being drawn into controversies regarding the origins of or the reasons for "problemshifts" or paradigm changes. Also, the science paradigm as outlined here, presupposes the acceptance of inductive as well as deductive "truth" without debating which is "more scientific" in the sense of the criticism levelled against "subjective truth" by the logical reconstructionists.

0020–7373/79/050651+13 $02.00/0 © 1979 Academic Press Inc. (London) Limited

Establishing definitions for what constitutes "truth" and defining criteria for evaluating truth also constitute thorny philosophical questions which are beyond my intentions here. Within the limited confines of this paper, solutions obtained from problem-solving methodologies shall be labelled "truths". And it is assumed that to be valid, "truths" should (1) meet criteria of internal coherence, (2) correspond as far as possible with perceived external reality (3) be accepted by their recipients and (4) be morally justified. What constitutes a "morally acceptable" solution is another issue which is side-stepped.

3. The science paradigm

The science paradigm embodies the scientific method which originates with Descartes and Rationalism and which has led both to the development of the "hard" sciences such as physics and chemistry and to the role of science and technology in modern life.

The science paradigm has been described as a "learning system" characterized by *reductionism, repeatability* and *refutation* (Checkland, 1976):

> "We . . . *reduce* the complexity of the variety of the real world in experiments whose results are validated by their *repeatability*, and we . . . build knowledge by the *refutation* of hypotheses."

The steps of the scientific method have been described in many forms.

1. *Observations* are made after the phenomenon to be studied is defined.
2. A *hypothesis* is postulated within a theory which seeks to explain the relationship among the observed variables.
3. An *experiment* is designed to test the hypothesis and "validate" the theory.
4. If the hypothesis holds, the theory is accepted *as an explanation* of the observed events.
5. Generalizations, or *laws*, leads to *predictions* of future states.

The scientific method and its paradigm have been successful when applied to fields of "organized simplicity" or of "unorganized complexity" as found in domains of the physical sciences, the so-called "restricted sciences".

Two systems methodologies which embody the science paradigm are Operations or Operational Research, and Systems Engineering and the Classic Systems Research approaches.

3.1. OPERATIONS OR OPERATIONAL RESEARCH

(a) *Name of field*
Operations or Operational Research (OR) can be defined as the application of quantitative methods to decision-making, in particular, *the use of mathematical models for optimization.* Many procedures dealt with in management science, decision science etc. can also be called Operations Research. The field dates back to World War II when efforts were made to find optimal solutions for allocation, logistic and transportation problems in military operations.

(b) *Nature of domain*
In a general sense, OR applies to any domain. However, due to the very nature of its paradigm which defines precise system boundaries, the solutions obtained are only valid for the closed system over which the solution is formulated.

(c) *Problems to which suited*
The method of OR is best suited for well defined and well structured problems such as are found at the *operational* or *tactical* level. This means that it is probably better suited to "hard" rather than "soft" systems, where the "hard–soft" dichotomy refers to its physical-mechanistic versus its biological-behavioural content.

(d) *Application of the paradigm*
In OR, the science paradigm is slightly modified. Several alternatives (instead of a single *hypothesis*) are postulated as possible solutions or paths leading to achievement of the defined objectives. A *decision model* evaluates alternatives. The model is tested to check whether it is a good *explanation* of reality. The solution is evaluated by comparing system performance before and after the chosen alternative is incorporated in the system. The solution is then implemented and maintained.

(e) *Nature of solution*
Within the system defined by the assumed boundaries (or constraints) the model yields an optimum solution.

(f) *Criteria for "truth" evaluation*
In OR models, it is usual to formulate *objective functions* in terms of the *measures of effectiveness* embodying the modeler's goals, these being normally those of the decision-maker who is being helped by the study.

(g) *Proof of "truth"*
The OR model is "self-serving" or tautological, in that it provides the function by which the solution can be tested for optimality. It does not offer a guarantor *outside* the model, apart from the attempts at evaluating the correspondence between model and reality and the improvement between the old and new systems. (The lack of guarantor leads directly to the need for introducing a metasystem in which the desirability and effectiveness of the proposed solutions can be arbitrated at a systems level above that of the model under study, i.e. at the *metasystem level.* We will return to this point later.)

3.2. SYSTEMS ENGINEERING AND CLASSIC SYSTEMS RESEARCH METHODOLOGIES

(a) *Name of field*
The differentiation between this methodology and Operations Research is one of scope and of degree. If there is a difference, it resides mostly in the claims of its proponents or adepts. The methods of Operations Research are similar to those used in Systems Engineering and related systems methodologies to which the name Classic Systems Research methodologies has been given (Open University, 1976). Systems Engineering (SE) looks at reality broadly and thus accepts the ill-structure of domains. In its pure form, the application of OR models can only be made to well structured systems whose attributes are specific and well defined. SE claims to embrace "the total system research problem" (McGrath, Nordlie & Vaughan, 1973). Thus SE has been defined as:

> An approach involving analysis planning and design with a view of selecting the best alternative, policy or course of action by which the systems performance requirements can be met (Quade & Boucher, 1968).

(b) *Nature of domain*
In SE, the problem setting is enlarged to embrace ill-structured domains. The influence of general systems theory is beginning to be felt when it is claimed that "one strives to

look at the entire problem as a whole" (Quade & Boucher, 1968). In preliminary research stages, SE questions the "total program of work" around a problem in order to assess "the immediate area of need" as well as a "range of environmental factors" (Hall, 1962).

(c) *Problems to which suited*
SE is suited for tactical problems as well as those with strategic implications. SE attempts to discern the existence of the "soft" system components in a problem, but its degree of success in dealing with them must be rated poor.

(d) *Application of the paradigm*
The SE methodology can be characterized as the application of the Operations Research methodology at the level of the entire system and at that of each of the sub-systems. The sub-systems can be sub-problems of the main problem or the several phases of it. The iterative process by which the problem is formulated, objectives are defined, measures of effectiveness chosen, alternatives generated and evaluated prior to policy selection still relies heavily on the traditional scientific method.

(e) *Nature of solution*
Alternatives are ranked by using the criteria chosen for evaluation.

(f) *Criteria for truth evaluation*
In older versions of SE, alternatives were ranked according to criteria involving costs, benefits and effectiveness. Recently more sophisticated multicriteria decision models incorporating worth functions have improved the previously narrow evaluative process by which alternatives were compared.

(g) *Proof of truth*
Cost benefit analysis is open-ended and thus does not provide any guarantee of truth. Thus, the wide ambitions of Systems Engineering and of the Classic Systems Research methodologies have not been realized. Providing decision-makers with ordered alternatives overlooks the *criterion problem* (which criteria are to be chosen), the *problem of interpersonal comparison* (how do we compare individual preferences), *the problem of consensus* (how can preferences be aggregated), and the problem of *implementation* (will the chosen solution be accepted by recipients).

4. The systems paradigm

The systems paradigm is no less scientific in a broad sense than the science paradigm or the metasystem paradigm. They all are scientific in that they employ rational models of reasoning: they all proceed either by induction or deduction from premises to conclusions. They all emerge in the same tradition of rational western thought.

The systems paradigm takes into account the indivisibility of systems domains where "organized complexity" prevails. It originates from concerns that the science paradigm, which was designed to deal with the physical world, breaks down when faced with living systems. These entities are characterized by openness, low separability and high interdependence. This precludes the possibility that parts be treated in isolation since the parts when aggregated, display *emergent properties* (Checkland, 1976).

Thus reductionism and the logico-analytical framework of the science paradigm must be modified and complemented by a new approach whose foundations can be found in the new discipline of general systems theory.

At present, there is no unique systems paradigm which can be offered as a counterpart to the science paradigm. Several authors have described and/or used approaches which constitute a step towards a systems paradigm. The systems paradigm offered by van Gigch can be criticized for using an approach which is rather closely bound to the traditional scientific method and science paradigm (van Gigch, 1978). It also uses "hard" systems engineering terms such as "design", "optimization", "implementation", terms which are not representative of the "new learning system" pioneered by Checkland (1972, 1976).

Whereas van Gigch considers the systems paradigm as a "fluid cybernetic process" where systems design functions are applied to a problem, Checkland limits himself to finding basic (systems) inadequacies in a situation in which a problem is perceived as a prelude to defining desirable and feasible changes which could lead to possible improvements.

4.1. APPLIED SYSTEMS ANALYSIS AND APPLIED GENERAL SYSTEMS THEORY

(a) *Description of field*

Applied systems analysis is the name I shall give to the methodology which has evolved in the work carried by P. B. Checkland and his colleagues at the University of Lancaster, England. *Applied general systems theory* is the name given by van Gigch (1978) to his brand of the systems approach. The two methodologies have moved in the same direction, and the work done at the Open University, England, by the Systems Course Team can also be associated with this school of thought which straddles the "hard" systems methodologies represented by OR and SE described above and the "soft" systems methodologies which derive their orientation from the life sciences and which will be described in subsequent sections.

(b) *Nature of domain*

Checkland and van Gigch are attempting to cope with the unstructured or ill-structured problems of the real world which exhibit the "emergent systems properties" of wholes. They assume that socio-technical systems are endowed more with the characteristics of biological than of physical systems. We are here dealing with systems of "organized complexity" which cannot be dealt with by the traditional scientific method which assumes systems with high separability and low interaction among parts. Checkland tends towards a view of human behaviour and organizations as not necessarily goal-seeking but rather as maintaining "on-going relationships" in the context or *climate* of what Vickers (1965) has called "appreciate systems". Thus he favours the description of a problem situation as having elements of *structure* which refers to the relatively slow-to-change features and the constantly-changing elements of *process*. The "*climate-structure-process*" approach constitutes the basis for a learning system by which the problem situation is iteratively explored and perceived (Checkland, 1972).

(c) *Problems to which suited*

This methodology, in particular Checkland's approach, is decidedly designed to tackle practical real world issues. The University of Lancaster group have applied their methodology to more than 100 systems studies. The Open University System Course

Team have applied it to the study of systems performance and failures (Open University, 1976).

(d) *Application of paradigm*
Checkland's version of the systems paradigm consists of a process by which conceptual models of systems relevant to the problem situation studied are built via *root definitions* which are descriptions of the six basic characteristics of the system, i.e. (1) ownership; (2) actor(s); (3) transformation process; (4) customer; (5) environment and (6) world-view.

The conceptual models embody the *minimum essential activities* by which the systems can be represented. By comparing the models with reality and challenging the extent to which they are a faithful image of the present reality, modifications and changes to the system are suggested, designed and implemented (Smyth & Checkland, 1976).

Van Gigch's version of the systems paradigm is described as a cycle or "cybernetic fluid process" consisting of basic design functions by which soft systems can be fashioned. While claiming to owe its foundations to general systems theory, van Gigch's methodology suffers perhaps from incorporating too many vestiges of "hard" systems engineering such as "design", "optimization", "implementation" and the like. In contradistinction with Checkland (1972, 1976) and Popper (1957) who defend incrementalism and piece-meal engineering, van Gigch argues in favour of Popper's *Utopian engineering*, that is solutions at the level of the global system. Whether these solutions can always be found or even formulated is not always clear. Checkland's more limited vision of the Systems Approach may have the decided advantage of practicality.

(e) *Nature of the solution*
Checkland's methodology yields partial desirable *changes* when the conceptualization stemming from the root definitions conflicts with the perceived present reality. In van Gigch's methodology a solution is the output of the systems design process applied at the scale of the total system.

(f) *Criteria for truth evaluation*
In Checkland's scheme, changes to the system must meet two criteria. They must be *desirable* and *feasible*. The more comprehensive approach advocated by van Gigch somewhat clouds the issue of the specific criteria to be met. He favours the use of multidimensional decision models where more than two criteria can be satisfied. This calls for compromise and trade-offs, a not too unrealistic representation of the real world. He also calls for the incorporation of ethical considerations in the calculus of system optimization. In Churchman's (1968) terms, systems science must be "self-reflective" and evaluate the results of its own deeds.

(g) *Proof of truth*
For Checkland the choice of a desirable change stems from a comparison between the conceptual models stemming from root definitions and the world view of perceived reality. Thus *consensus* provides the guarantor of truth. Consensus is also invoked by van Gigch as a necessary ingredient of truth but its practical validity may be lost when dealing at the scale of the global system.

In summary, the methodologies dealt with in this section move systems science in the direction of holistic thinking and they are useful complements to the more traditional approaches described earlier. Checkland's approach goes a long way in answering the need for a practical methodology tailored to soft-systems domains. Its lack of theoretical foundation may prove a disadvantage in the future if more progress is to be made in conquering the methodological dilemmas confronting it.

4.2. THE METHODOLOGY OF DIAGNOSIS

In this section two theories which exemplify the methodology of *diagnosis* are given. This methodology has been developed for the most part in the medical sciences and of late has been applied to other fields. For surveys refer to Pipino (1975) and Bouwman (1978). It is clear that the methodology of diagnosis can be used in both contexts, the science and the systems paradigms. It is presented at this point because the two theories chosen for illustration are holistic in nature and are in that sense representative of the systems paradigm.

The methodology of diagnosis proceeds as follows.

1. Given an entity perceived as system, acceptable and unacceptable system *states* are defined.
2. Features, attributes or patterns of behaviour are extracted to generate categories or classes.
3. Observations from the system under study are assigned to classes defined earlier.
4. In the *detection phase*, a decision is made whether the system is in an acceptable or unacceptable system state.
5. In the *diagnosis and evaluation phase*, the unacceptable system state(s) is identified.
6. In the *treatment phase*, the unacceptable system state is restored to one which is acceptable.
7. In the *control phase*, a prediction or *prognosis* is attempted, to determine whether the system will remain in an acceptable state or will lapse back to an unacceptable one (Pipino, 1975).

The intent is to define a good *descriptive* model, that is, one which is a faithful representation of reality. The model is then used in a *normative* sense to describe how the system *ought to be* and against which an actual system or situation can be compared to detect unacceptable departures.

The crux of the successful application of this methodology resides in having a model which can be used in the *dual descriptive-normative role.* Two models which may potentially be used to achieve this purpose are described below:

1. Miller's general systems theory of living systems, and
2. Autopoieses.

4.3. A GENERAL SYSTEMS THEORY OF LIVING SYSTEMS AND AUTOPOIESIS

(a) *Description of the field*

1. *Miller's general systems theory of living systems.* J. G. Miller (1975, 1976, 1978) has developed a general systems theory which describes isomorphisms across seven levels of living systems. These are cells, organs, organisms, groups, organizations, societies and supranational systems. He has conceptualized nineteen (19) basic energy-matter-information processing subsystems which he claims are common to all levels. This

theory can be considered a problem-solving methodology to the extent that it provides a descriptive-normative model against which actual systems can be compared, as done by Vandervelde & Miller (1975).

2. *Autopoiesis.* Autopoiesis can be considered a more advanced general systems model of living systems which originates in theories of microbiology (Varela, Maturana & Uribe, 1974; Maturana, 1975). In the same sense as Miller's theory, it can be termed "a paradigm of inquiry" in that living systems can be studied, their properties simulated and the effects of specific environmental perturbations monitored by means of the model of the process of autopoiesis. Some proponents of autopoietic systems contrast Miller's model to theirs and claim his to be obsolete (Zeleny, 1977).

(b) *Nature of domains*

The use of both Miller's theory and autopoiesis is concerned with the description of living systems whose processes can be studied in order to find identities and/or departures from those postulated in the models. Thus these models lie in the realm of "soft systems" and may help us understand better the organizational and behavioural characteristics of the real world.

(c) *Application of the paradigm* not discussed.

(d) *Problems to which suited*

1. Miller has developed his theory and model to encompass the seven levels of living systems. Thus one could take systems displaying any or all of these levels and determine whether they function in the form presented by the model. The model probably offers most promise at the highest levels of complexity such as those exemplified by organizations, societies and supranational systems. As yet, we do not have very good descriptive models of these entities. Miller's characterization may be well suited to evaluate how socio-technical systems and their component sub-systems operate.

2. Autopoiesis is too new as a field of endeavour to judge how it will be developed and applied. Reference has been made to simulation studies by which the effect of environmental perturbations upon intricate phenomena occurring in the processes of cells can be studied and modelled (Zeleny, 1977). Whether, as claimed, these processes can be transposed to higher levels to explain processes in higher living organisms is subject to conjecture.

(e) *Nature of solution*

In the context of the methodology of diagnosis, a solution (or "truth") consists in recognizing the unacceptable state of a system and finding ways to restore it to an acceptable one. Thus a *solution* is obtained when the right diagnosis of ills and the correct treatment have been formulated. Good descriptive models to which actual systems in disarray can be compared, can offer potential for improving diagnosis. It is open to question whether they can provide hints for appropriate treatment.

(f) *Criteria to evaluate truth*

In diagnostic models, a "solution" can be evaluated by:

(1) the costs involved in obtaining proper diagnosis;
(2) the extent to which unacceptable states depart from desired acceptable ones;
(3) the costs involved in restoring the system back to acceptable states (Gorry & Barnett, 1968*a,b*).

(g) *Proof and guarantee of "truth"*
A solution is reached when the system which starts from an unacceptable state is restored to an acceptable state. Thus the diagnostician is dependent on a good model which clearly discriminates among system states and whose patterns and features can be easily recognized. Of course treatments may have unexpected effects *outside* the system. Who then is the guarantor remains an open question.

5. The metasystem paradigm

The metasystem paradigm originates in the premise that one cannot arbitrate deficiencies among systems in other than a metalanguage, that is in the language of a metasystem which lies at a system level *above* that of the systems whose control is sought. Beer exemplified the concept of a metasystem by suggesting isomorphisms between the physiology of the brain and the hierarchy of control used in the firm (Beer, 1972). The concept of metasystem can also be found in the conceptual model of problem-solving systems ideals predicated by Klir (1976), Klir & Uyttenhove (1976), Ulrich (1977) and earlier in Churchman (1971).

(a) *Description of the field*
1. *A cybernetic metasystem model.* In *Brain of the Firm*, Stafford Beer (1972) suggested that the organization could be modelled as a hierarchy of control systems patterned after the neurophysiology of the brain. This was followed by *Platform for Change* (Beer, 1975) which can be considered a cybernetic metasystem model. It is *cybernetic* because it features feedbacks, and it is a *metasystem* because it represents a system to design other systems.
2. *A conceptualization of problem-solving processes design ideals.* The school of thought initiated by Churchman and exemplified by Mason (1969), Mitroff & Betz (1972), Mitroff & Sagasti (1973), Mitroff & Turoff (1973), Mitroff (1977), Mitroff, Barabba & Kilmann (1977) and by Ulrich (1977) integrates problem solving methodologies into a hierarchy of problem-solving systems. This hierarchy is a general system model of design. It is devoid of content in the sense that it can be applied to all systems. It can be construed as the conceptualization of Beer's idea of the metasystem which can be used to design any other system.

(b) *Nature of domain*
The metasystem paradigm deals with epistemological questions. It is concerned among other things with the design of a paradigm by which all other paradigms are designed.

(c) *Problems to which suited*
A design metasystem is devoid of content in that it addresses itself to the problem of judging other methodologies. It is not problem oriented but constitutes an inquiring system by which methodologies for solving problems are designed.

(d) *Application of the paradigm*
Klir (1976) conceptualized a hierarchy of epistemological levels of systems which are differentiated by the level of knowledge about a set of variables in the system, about potential states associated with each variable and their constraints. "A higher level system entails all knowledge of the corresponding systems at any lower level and

contains some additional knowledge which is not available at lower levels". Klir defines six levels.

1. *The source system* where systems at this level are defined as sources of available data.
2. *The data system,* when a source system is supplemented by data.
3. *The generative system,* which provides a basis for generating data.
4. *The structure system,* which consists of a set of generative systems or lower level systems embedded in the larger system and which display relations or couplings among its elements or components.
5. *The meta system,* a level at which systems are defined by a set of structure systems or lower level systems and an invariant procedure which describes transitions between those systems.
6. *The meta-metasystem,* containing all the metasystems and which can be defined by "assuming an invariant metaprocedure describing transitions between the procedures of the metasystems".

Klir and his co-workers have performed data systems experiments in which this conceptual framework has been operationalized (Klir & Uyttenhove, 1976; Broekstra, 1976, 1977).

In a similar vein, Ulrich (1977) conceptualized problem solving as a hierarchy of three basic subsystems.

1. At the bottom, an *information system* whose basic function is to produce *knowledge* (called the methodological question) for a higher level system called the *action system*.
2. The *action system*'s role is to question *how* knowledge is applied (the pragmatic system). The action system is a metasystem with respect to the information system.
3. The *ethical* or *value system* is a metasystem with respect to the action system. It evaluates the uses to which knowledge is placed.

In Beer's terms the organisation as a total system is a hierarchical structure of systems which requires:

(1) organisation to handle complexity;
(2) science to manipulate knowledge;
(3) cybernetics to redesign itself according to a continually changing model;
(4) a metasystem measure by which the outputs of subsystems can be evaluated;
(5) tools to handle the information flows by which organisations are managed;
(6) ethics to manipulate change with compassion (Beer, 1975).

The concept of metasystem also appears in policy-making and planning science. Dror (1968, 1971) explicitly distinguishes between metapolicy-making, policy-making and postpolicy-making. Metapolicy-making is described as the way to improve the policy-making system, that is, policy on how to make policy. Faludi (1973) discerns between three levels in planning theory namely metaplanning, procedural and substantive theories of planning. Some initial hypotheses about the theory of metaplanning are developed by Emshoff (1978). Designing the metasystem for organizational decision-making is the subject of a forthcoming paper (Kickert & van Gigch, 1978).

(e) *Nature of the solution obtained*
The metasystem paradigm incorporates epistemological characteristics which are lacking in the two systems paradigms discussed above. In particular it includes:

(1) a hierarchy of problem solving levels in which higher system levels can judge and rate solutions for lower systems levels;
(2) a framework to provide evaluation criteria in a metalanguage terms, i.e. in a language appropriate to judging lower system solutions;
(3) a guarantor of truth at each system level, always excepting the last (or highest).

(f) *Criteria to evaluate truth*
Beer's work shows that we need metasystem criteria to judge lower system propositions. Decisions in one system must be reformulated in the metalanguage. The metasystem, for example, must evaluate how lower level systems apply technology to produce waste as well as wealth. It must also be in a position to evaluate the ethical implications of the various systems designs, an issue which is embodied in the Morality of systems (Churchman, 1968; van Gigch, 1978).

(g) *Proof of truth*
Truth can only be evaluated in metalanguage terms and can only be judged from the vantage point of the metasystem. Neither of the two paradigms previously considered could guarantee the nature or validity of their solutions because they lacked a metasystem from which this could be done. The science paradigm can only judge optimality in the context of the very model which produced the solution. The systems paradigm relied on consensus, a mild form of review by a higher system. In the diagnostic system, evaluation was tautological in that departure from the norm was a function of the adequacy of the descriptive model which was turned into a normative one for purposes of comparison and evaluation—thereby an empty proof.

6. Conclusions

This study compares three systems paradigms by which we design methodologies for problem solving.

Attempts at designing a methodology suitable for soft systems domains overlook the need to deal with issues such as the choice of criteria by which solutions can be evaluated, and the need for a guarantor for truth.

In OR, solutions are only valid in the context of the model by which they are optimized, in Systems Engineering the solutions are open ended. In present versions of the systems paradigm allusions to consensus and ethics show the trend toward requiring higher level systems by which other systems can be evaluated. The concept of the metasystem paradigm partially answers these criticisms but, even within that concept, there can be no higher-level guarantor for the highest level conceptualized. This is a major paradox for systems thinking, as Churchman (1968) has pointed out.

I would like to thank those who commented on earlier versions of the paper, which in the Fall 1977 was delivered to the following: University of Lancaster, Department of Systems, Lancaster, U.K., University of Essex, Department of Electrical Engineering Science, Colchester, U.K., The University of Aston, Management Centre and Department of Psychology, Birmingham, U.K., City of Birmingham Polytechnic, Department of Business Studies and

Finance, Birmingham, U.K., The City University, Department of Systems Science, London, U.K., and Imperial College, University of London, Department of Management Science, London, U.K. I also discussed this paper with colleagues at the Anglian Regional Management Centre, North East London Polytechnic, Danbury Park, Essex, U.K. and the Department of Industrial Engineering, Eindhoven University of Technology, Eindhoven, the Netherlands. The reference Open University (1976) contains a discussion of methodologies which was instrumental in initiating this dialogue.

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