OMEGA, The Int. Jl of Mgmt Sci., Vol. 1, No. 6, 1973

Operations Research from the Viewpoint of General Systems Theory

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(Received March 1973; in revised form June 1973)

This paper examines the operations research process from the viewpoint of General Systems Theory. The components of the OR process and the relations between them are critically examined. The five components are: (1) the "reality" of the problem situation, (2) the conceptual model of the problem situation, (3) the scientific model of the conceptual model, (4) the solution to the scientific model, and (5) the implementation of the solution. The paper argues that we have sub-optimized both our knowledge (study) and our application of the OR process. That is, there have been extremely few studies and applications of OR which have concerned themselves with OR from a whole systems point of view.[2] The paper argues that without a whole systems perspective OR can neither be understood nor effectively applied.

INTRODUCTION

IN THEIR paper "General systems from an operations research point of view", Sengupta and Ackoff [25] showed how it is possible to study systems in general by describing their properties in operations research terms. They pointed out that General Systems Theory (GST) can profit a great deal from what has been learned in operations research. In this paper the opposite (but complementary) approach is taken; operations research is examined from a general systems point of view, with the aim of showing that our understanding of the OR process can thereby be improved.

General Systems Theory is concerned with the study of systems from a "holistic" point of view. It postulates that there exist a number of properties

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[2]Churchman [9] and Emery [12] provide excellent summaries of systems thinking. Buckley [7] has edited a very good sourcebook on systems theory and its relation to the behavioural sciences.

of systems that cannot be described and examined meaningfully in terms of the properties of its constituent elements. Using Churchman's [8] terminology, GST is concerned with the study of *whole systems* as opposed to *atomistic systems*. GST further postulates that these "holistic" properties are common to a large number of systems and that their study can provide us with useful insights, and in some cases, concrete methods and tools of analysis [22].

A SYSTEMS VIEW OF THE OPERATIONS RESEARCH ACTIVITY

Relatively few operations researchers have studied OR as a whole system considering it as an advice generating process. A majority of those writing on or about operations research have concerned themselves with some particular aspect of it.[3] Their view of the OR process is largely implicit. It is more implied by the specific aspects of the process with which they are concerned rather than stated explicitly.

From the vantage of GST, we consider the activity of OR as a system with several component subsystems and we are concerned with the relations between them. These subsystems are of a conceptual nature and correspond to some phase of the operations research process. Furthermore, the component subsystems exist *only* by virtue of their relation with one another; they do not have any meaning if examined on their own. We consider each of these subsystems as follows.

When facing a problem situation or *reality*, the operations researcher constructs a mental image corresponding to it. Following Beer [3, 4] we call this mental image the *conceptual model* of the problem situation. From this conceptual model, the operations researcher then proceeds to develop a formalized representation of reality, usually in symbolic terms and containing the variables and parameters judged relevant. The formalized representation is called the *scientific model* of the problem situation.

Using the solution techniques and procedures that are available to him, the OR analyst extracts a *solution* from the scientific model, which will be communicated to a decision maker. The operations researcher draws heavily on his scientific training when constructing the conceptual model, the scientific model, and when deriving a solution from it. Thus it can be said that *science* provides the general background for the activites of the operations researcher.

Each of the concepts underlined above can be considered as a subsystem of the operations research process. They will be examined in further detail.

The subsystem named *reality* consists of all the aspects of the real world that concern the problem situation. All the unorganized perceptions of the OR analyst regarding the problem situation belong here. These perceptions are

[3]Churchman [9], Ackoff [1], Beer [3] and Morris [23] constitute notable exceptions.

acquired through observation. "Reality" provides all the data and initial imputs to the operations researcher. It constitutes the starting point for the OR process. However, it is obvious that different observers may see different "realities" and that the very concept of reality itself contains value judgments: it does not exist independently of the observer [10]. We shall not explore this concept further for the time being but will return to it at the end of this paper.

The *conceptual model* subsystem is defined as the "mental image" that the operations researcher forms in his mind about reality. It provides an orderly framework within which the OR analyst can and will place all his perceptions pertinent to the problem situation. Here is where the operations researcher identifies the structure of the problem and decides which aspects are relevant and which are irrelevant. The conceptual model represents a further degree of abstraction from reality and is capable of generating one or more scientific models.

The subsystem we have called the *scientific model* is the most widely studied and recognized element of the operations research process. It is a formalized representation of both reality and the conceptual model, and its correspondence to them is the most critical link of the OR process. It usually consists of a set of symbols together with a set of rules to manipulate them, although at least two other kinds of scientific models have been identified in the literature: iconic and analogue [2]. By manipulation of the scientific model, the OR analyst is able to assess its internal consistency, establish its degree of correspondence with reality, and to extract a solution from it.

The *solution* can be considered as the output subsystem of the OR process. It is obtained from the scientific model and constitutes the basis for the recommendations and the advice the operations research practitioner gives to the decision maker.

Science can be considered as the subsystem of the OR process which provides the basis for all the interrelations among the other four subsystems. It provides the OR analyst with a repertoire of concepts and ideas in terms of which to look at reality and elaborate the conceptual model. It provides the necessary scientific methodology to proceed rigorously from the conceptual to the scientific models, and the tools for constructing it. Science also provides the methods by means of which a solution can be extracted from the scientific model and the standards for establishing its correspondence with reality. Finally, science and the social sciences in particular, provide the OR analyst with guidelines to follow during the implementation phase.

The preceding paragraph contains an outline of the types of relations we find between the different subsystems of the operations research process. These relations are all shaped by science in the sense that scientific method provides the canons by means of which the links between subsystems are (or should be) established. We now examine in more detail the character of these relations.

The link between reality and the conceptual model is established through a *conceptualization* process. The conceptual model is generated mainly by what

Vickers [28] calls *acts of appreciation* and what Beer [4] calls a process of *analogy*. The operations researcher approaches the problem situation having in his mind a baggage of ideas, concepts, anticipations and expectations which may be considered as his "knowledge", "experience", or "scientific background". Reality is not projected on an empty mind. The existence of those concepts with which he is more familiar and conversant will allow him to establish an analogy with the problem situation. Indeed, his background may even determine whether what he sees constitutes a problem situation or not.

Few operations researchers have written about the role of the conceptual model and the way it is generated. This is perhaps the most important and least studied phase of the OR process. For this reason, it will be examined in more detail in the next section.

The relation between the conceptual and the scientific models is established by means of the *modeling* activity. Here is where the scientific method plays the most important role. In the transition from the conceptual to the scientific model, the OR analyst identifies the controllable and uncontrollable variables, defining them precisely in operational terms. The scientific model generated by the modeling process should be capable of being manipulated and of generating solutions. Ackoff [1] provides a thorough treatment of the subject and Ackoff and Sasieni [2] have identified five characteristic patterns of model building. These can be considered as distinct ways by which one can establish the relation between the conceptual and the scientific model or models.

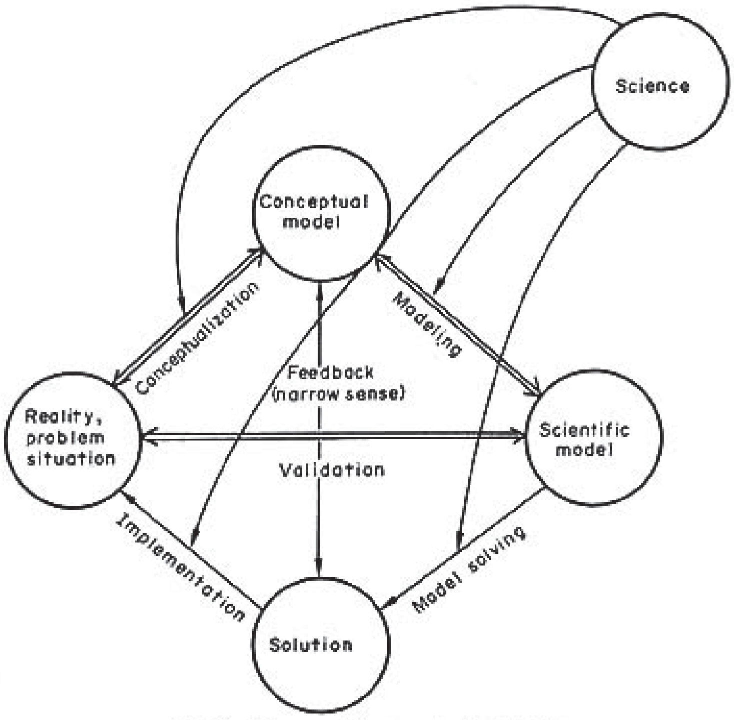
Once the scientific model is built, its degree of correspondence with reality or "accuracy" has to be established. This relation, which links the scientific model with reality can be labelled *validation*. It should not be confused with the validity tests aimed at examining the internal consistency of the model, which belong to the modeling phase.

The relation between the scientific model and the solution subsystems can, quite appropriately, be called *model solving*. A large amount of effort has been devoted to this aspect of the OR process which is discussed in detail in most OR texts.

There often exists another link which relates the conceptual model with the solution obtained from the scientific model. This link may be called *feedback* in a narrow sense, for it allows the operations researcher to test the coherence and relevance of the solutions obtained by contrasting them with his initial conceptualization of the problem situation. Feedback in a wider sense would require that the initial conceptualization of reality be also modified in light of the knowledge acquired while progressing through all the phases involved in the OR process.

Finally, the *implementation* of the solution can be considered as the relation which links this subsystem back with reality.

The diagram of Fig. 1 shows the subsystems and their relations to one another. The double lines linking reality, the conceptual model and the scientific model represent the critical aspects of the OR process; there must be a *correspondence* among these three subsystems if the OR process is going to contribute something at all to decision making. In a broader sense, all the subsystems are critical and cannot be ranked in priority or importance.



Fɪɢ. 1. *The operations research process.*

A CLOSER LOOK AT THE CONCEPTUAL MODEL

We turn now to a more detailed look at the conceptual model. Its importance and the relative lack of attention it has received from OR analysts justify the emphasis placed on it in this paper.

The late Professor Henry Finch used to say that we never face a problem with an empty mind, that in order to recognize problem situations as such we must have some prior idea about them: "if we did not know anything at all about a problem we would not even recognize it as a problem".

The background of ideas the OR analyst has in his mind is what allows him to perceive reality as a problem situation, and the conceptual model he constructs uses these ideas and concepts as building blocks. The process by means of which a particular conceptual model of the problem situation is selected among the many that could represent it may be considered as one of establishing analogies between familiar concepts and the less familiar problem situation. To a large extent, the difference between "reality" and the "conceptual model" would correspond to that customarily made between "data" and "information".

Boulding [6] has summarized this process of conceptualization in general terms:

> "When a man is faced with an empirical system of some kind he has an uncontrollable urge to produce a *mental system* or an image in his mind which is a model or an explanation of the empirical system he encounters. Empirical systems in the outside world are very complex and, as we all know, it is extremely hard to find out what is their true systematic nature. It is not surprising, therefore, that we argue by analogy from systems we know, to systems we think we do not know." [6, p. 32].

Substituting "problem situation" for "empirical system" and "conceptual model" for "mental system", we would have a description of the conceptualization process in operations research.

The development of a conceptual model requires an interplay between the empirical facts contained in the description of the problem situation and the mental images of the operations researcher. Vickers [28] has called these interplays between judgements of value and judgements of fact *acts of appreciation*: "An appreciative system is a net of which the weft and warp are reality concepts and value concepts. Reality concepts classify experiences in ways which may be variously valued. Value concepts classify types of relations which may appear in various configurations of experience." [28, p. 70]. Thus, the construction of a conceptual model to order the perceptions of the OR analyst about reality and the problem situation would constitute an act of appreciation which structures and delimits the areas of concern for the operations researcher. McWhinney [21] has also emphasized the need for developing "appreciative skills" to deal with what he calls "domain problems". For him, domain problems "deal with the questions of *what* aspects of the environment are to be of *concern*, of what phenomena should be *noticed* and of what variables should be introduced into the criterion of organization's performance." [21, p. 272]. The process of dealing with McWhinney's domain problems is similar to what we have called the conceptualization process.

It is clear that for a given problem situation many conceptual models could be elaborated. Almost certainly, *different OR practitioners would form different mental images of the same problem situation*. Indeed, this was one of the original reasons for OR's emphasis on interdisciplinary teams.[4]

[4]For example, the collection of essays edited by Churchman and Verlhurst [11] contain five different approaches to the modeling of inventory problems. The approach taken by a particular author could be easily inferred from his training and background.

For any given problem situation, the differences among the conceptual models of several operations researchers may arise not only because of different backgrounds or appreciative systems but as Churchman [10] and Mitroff [22] emphasize, they may also arise from different epistemological approaches held by the researchers. This point has been developed fully in Churchman's *The Design of Inquiring Systems.* According to Mitroff [22]:

> "to represent (conceptualize or model) a problem *is* to conduct an inquiry into its nature . . . to conduct an inquiry into a problem is to gather (or produce) some information on it. In this sense, information is not separable from inquiry (or epistemology) because what we know (i.e. information) about a problem (i.e. its nature) is not independent of how we have obtained that knowledge, i.e. of the particular inquiring system we have adopted . . . Because information is thus so closely tied to inquiry, *The Design of Inquiring Systems* can be thought of as an exploration into the design of archetypal, philosophically-based information systems. To model a problem is to present information on its nature to some decision-maker who is (or may be) required to take action on the problem." [22, p. 9].

Churchman [10] identifies five archetypal kinds of inquiring systems: Leibnizian, Lockean, Kantian, Hegelian and Singerian. Very briefly speaking, Leibnizian inquiring systems are the archetype of abstract, formal, mathematical or logical inquiring processes. Lockean inquiring systems are the archetype of the experiential, data-gathering, consensual inquiring processes. Kantian systems are the archetype of multi-disciplinary, integrative processes of inquiry; they attempt to use both formal theory and data matched to the theory in order to build multi-models of any phenomenon. Hegelian inquiring systems are the archetype of conflictual inquiring processes; they attempt to generate the strongest possible debate by building opposite and strongly conflicting models. Singerian systems are the archetype of scientific–ethical integrative inquiring processes; they attempt to identify both the scientific and the ethical components of any system or problem.

Based on Churchman's analysis of these various inquiry systems, one would expect that the stance adopted by the operations researcher, whether explicitly or implicitly, with regard to the inquiring system he uses in the OR process, will influence heavily the way he constructs the conceptual model of a given problem situation.

The fact that many conceptual models may correspond to a given problem situation poses the additional problem of deciding how to build a "good" or "workable" (notice we do not say "best") conceptual model, and how to determine its characteristics. There are few scientists who propose rules on how to construct conceptual models and/or provide criteria for evaluating alternative conceptual models for a given reality.

Boulding [6] proposes that a conceptual model, or "analogy" as he calls it, should be evaluated in terms of the system which is derived from it, or in our terms, the scientific model. Unfortunately, one conceptual model may generate many scientific models, some of which could be "good" and some "bad"; therefore, it is not possible to apply rigorously the criterion he proposes, for there is not a one to one transformation between them. Bertalanffy [5] proposes a scheme in terms of analogies and homologies, but it amounts to little more than statements on definitional differences. Forrester [13] acknowledges the existence of what he calls "mental models" (our conceptual models) but dismisses all of them as practically useless. Simon [26] deals explicitly with conceptual models, but does not propose ways of evaluating them. Beer [4], despite his treatment of the subject from an OR point of view and his analysis of homomorphism, also falls short of proposing a method for assessing the validity and fruitfulness of alternative conceptual models.

Hesse [14] has written extensively on the subject of analogy in a more general context than the one we are dealing with here. She distinguishes three components of an analogy: the positive, negative and neutral aspects. The positive components are those properties of the analogy which directly correspond to those of the reality under scrutiny; the negative components are those properties which do not correspond to the problem situation, and the neutral ones are those which do not have an apparent relation to the problem on hand. The latter supposedly lead to new insight into the problem situation.

A good conceptual model from the operations research point of view would be one that has no negative components and in which there is a balance between the positive and the neutral aspects. If this were the case, the OR analyst would be able to construct an adequate conceptual model by virtue of the positive components and to obtain new insights and guidance for research from the neutral aspects of the conceptual model or analogy.

Unfortunately, the problem of determining which are the positive, the negative, and the neutral components of the analogy remains unsolved. Hesse does not provide an answer to this problem, and it is thus necessary to say that we do not have available at the present moment a clear, precise, or operational way of deciding whether one conceptual model is better than another. Perhaps this conceptualization process is a part of the "art" of operations research rather than of the "science" of OR, and maybe it should remain this way.

SOME IMPLICATIONS OF A SYSTEM'S VIEW OF THE OR PROCESS

The conceptualization of the operations research process offered in the previous section suggests several lines of inquiry which could improve our understanding of the practice of OR.

A first observation refers to the relation between different psychological types and the different phases of the OR process. Hudson [16] has identified and described two kinds of conceptualizers: the *converger* and the *diverger*. In general terms, convergers tend to prefer to work on manageable, well-defined problems for which there exists a single "best" answer. They also tend to select one of a set of alternatives and develop it in detail. Divergers tend to prefer to work on vague and ill-defined problems for which there exist many alternative approaches. They prefer to multiply alternatives and possibilities rather than develop any single one in great detail. Convergers are analytical, they are "parts" oriented. They tend to perceive systems as separable. Divergers are synthetic, they are "whole systems" oriented, and they tend to perceive systems as non-separable. Hudson [16] suggests that most scientists tend to be convergers, and that most arts and humanities students tend to be divergers. Hitt [15] and Maslow [19] have identified the characteristics of these two psychological types and derived their implications for the psychology of science.

In terms of our conceptualization of the OR process, it is possible to say that the skills and traits of the converger type would be most valuable in the modeling and model solving phases. Beginning from an established and structured conceptual model, the converger oriented OR analyst would proceed rigorously to develop the scientific model.[5] In the solving phase, the converger generally finds the situation well suited to his psychological traits, for there usually are well established logical procedures to derive solutions from a given scientific model.

On the other hand, the skills and traits of the diverger type would be most valuable in the conceptualization phase. At this stage, it becomes important to develop several alternative conceptualizations of a problem situation, which would shed light on its different aspects and facets, and which would lead to a more complete picture of the different variables and parameters that affect it. The diverger would tend to construct many conceptualizations for a given problem situation, instead of locking himself to a particular kind of conceptual model. He would be concerned with opening up new possibilities and challenging established habits of thought.

The style and attitudes of the diverger would also be valuable at the implementation phase, for he is better suited to imagining and devising several alternative ways of making the results acceptable and/or putting them into practice. The diagram of Fig. 2 shows the relations between the phases of the OR process and the psychological types discussed. It goes without saying that the two types, the converger and the diverger, represent extremes that are useful for analytical purposes, and that most individuals combine some aspects of each type, although one of them will tend to dominate.

A second observation refers to the relation between another system of personality types [18] and the phases of the operations research process. The Jungian personality typology characterizes four major modes or psychological

[5]Although several scientific models could correspond to a given conceptual model, the converger would seldom develop more than one scientific model.

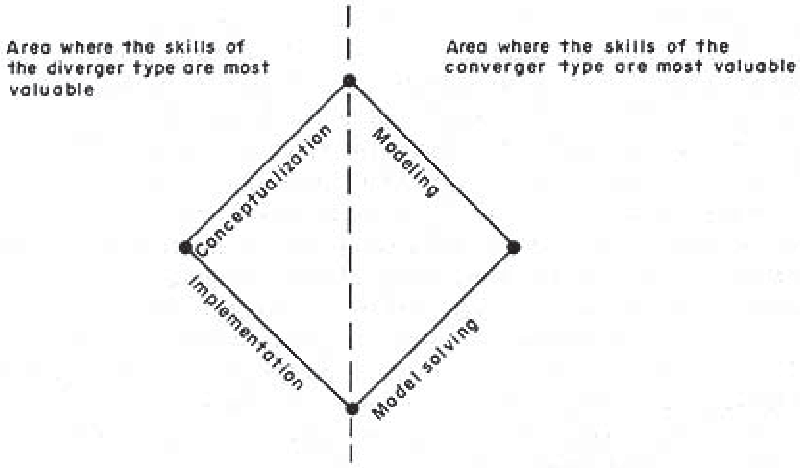


FIG. 2. *Hudson's psychological types and the OR process.*

functions. Two of the modes pertain to the dominant psychological functions that an individual uses to perceive the phenomena around him, and the other two modes pertain to the dominant psychological functions that the individual uses to evaluate the perceived phenomena. The alternative modes of perception are *sensation* and *intuition*. The alternative modes for evaluation are *thinking* and *feeling*. Most individuals tend to develop a preference for one mode of perceiving and one of evaluating, with the alternate mode remaining dormant [20].

A preference for sensation refers to that type of individual who relies primarily on sensory data in order to perceive the phenomena around him. Sensory processes, attention to detail, and reliance on "hard, objective data" dominate the way in which he approaches a problem situation. Intuition, on the other hand, refers to the mode of perceiving objects as possibilities. Whereas sensation perceives objects "as they are", in isolation, and in detail, intuition perceives objects "as they might be" and in totality, as a Gestalt. Sensation types are guided by the facts and are careful not to extrapolate them; intuition types see through "the facts" and are motivated to extrapolate beyond them.

With regard to the modes for evaluation, a preference for thinking implies that the individual relies primarily on cognitive processes. His evaluations tend to run along the lines of abstract true or false judgements and are based on formal reasoning. A preference for feeling implies the type of individual who relies primarily on affective processes. His evaluations tend to run along the lines of good or bad, pleasant or unpleasant, and like or dislike. He tends to make moral judgements. As in the case of the two perceptual models, the two evaluating modes also tend to be mutually exclusive.

It seldom happens that a pure personality type is observed. Individuals are far too complex to be classified in terms of just four modes alone. Nevertheless, these psychological types, considered as categories of analysis, provide a useful device for approaching the difficult problem of characterizing personalities and for deriving the implications of different personality types for a variety of activities, including operations research.

In effect, the systems view of the operations research activity offered in this paper can be related to the four personality types of Jung. For each of the relations linking the subsystems identified for the OR process, there would correspond one or more key psychological functions.

The functions of sensation and intuition would play the dominant role in the conceptualization phase which links reality with the conceptual model. The process of constructing adequate conceptual models (or establishing correct analogies, appreciative systems, homologies or homomorphisms), involves both the perception of "hard facts" through sensation, and the intuitive apprehension of global structures that would give meaning to these facts. The importance of sensation for the conceptualization process is generally well recognized. Less so is the importance of intuition, although Morris [24] has demonstrated the importance of intuition for management in general. Siu [27] has emphasized the need for intuition in understanding and handling a problem situation:

> "The ability to react with intuitive understanding at each step is a pre-requisite to rational analysis. The emergence of meaning is considered always a matter of logical intuition or insight. In real life this intuitive understanding is not built step by step, as in the case with logical discourse. Instead it is grasped as an immediate total apprehension." [27, p. 75).

The processes of modeling and model solving are dominated by the thinking function. Structured and well-defined reasoning procedures provide the means by which to proceed from the conceptual model to the scientific model, and from it to the solution. This is not to say that the other psychological functions are completely absent, but that they play a minor role in comparison with thinking.

The implementation phase involves primarily the functions of feeling and intuition. Affective and emotional processes often overshadow all the other aspects involved in the implementation of a solution. The relations between the OR analyst and the decision maker become the main subject of concern, and these are primarily shaped by feeling. Intuition also plays a major role, for the operations researcher must be able to grasp the structure of the situation he is acting upon, and of visualizing the way in which the proposed solution is likely to affect the decision maker and those involved in the problem situation under consideration. He must also be able to foresee the global implications of implementing the solution, particularly with regard to possible future problem situations.

Summarizing, the two modes of perception, sensation and intuition, play the dominant role in the conceptualization phase. One evaluation mode, thinking, plays the key role in the model building and model solving phases. Finally, one perception mode, intuition, and one evaluation mode, feeling, are of primary importance in the implementation phase (see Fig. 3). This implies that operations researchers who show a preference for different psychological functions would be inclined to work on and prove to be most useful in different phases of the OR process. Operations researchers belonging to different psychological types are likely to perform better in those phases of the OR process which are particularly suited to their preferences and psychological traits.

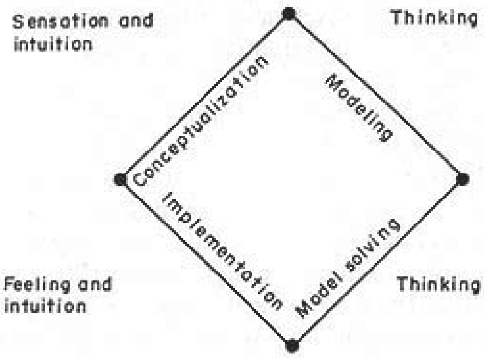


FIG. 3. *The Jungian psychological types and the OR process.*

The relations between the categories of analysis identified in two systems of personality types, that of Hudson and that of Jung, and the phases of the OR process, suggest another reason for emphasizing the need for diversity in forming OR teams. From this perspective, the criteria of multiple disciplines and varied backgrounds are not enough to form a good OR team. If all scientists and OR analysts from different disciplines were of the converger and/or thinking type, it is almost certain that the team would be unable to cope with vague and ill-defined problem situations, as most worthwhile problem situations are.

A further implication of the systems view of the OR process adopted here refers to a possible classification of the work of different OR analysts according to the number and the characteristics of the phases they tend to cover in their work. There have been operations researchers who have made their reputations by proposing a procedure to solve a particular scientific model with well-defined structural characteristics, but have not gone beyond doing that. Others have concentrated their efforts on the model building phase, and have shown the power of a particular class of scientific models to represent a large number of realities and/or conceptual models. Still others have been concerned primarily with the implementation phase, analyzing why solutions were or were not implemented. Relatively few have sought to deal with the conceptualization phase, as was pointed out earlier in this paper, and even fewer OR analysts have dealt with the totality of the operations research process.

The conceptualization of the OR activity developed here also has implications for the training of operations researchers. The education of an OR analyst should involve all the phases of the operations research process. Technical skills for model construction and model solving, which presently constitute the main area of concentration in most academic programs, should be complemented by the development of skills and capabilities appropriate for the conceptualization and implementation phases. Of particular importance is the development of a capacity for generating alternative conceptual models and for dealing with diffuse and complex problem situations. The inclusion of this aspect in academic programs would probably require a modification of teaching methods which rely on the use of structured "textbook" examples, and the introduction of areas of study dealing with unstructured real-world problems.

This analysis of the implications of the systems view of the OR process raises more questions than it answers. Alternative psychological categorizations could be analyzed in relation to the different phases of the OR process. The relation between different inquiring systems [10] and these phases could also be explored, and many other lines for speculation and research could be imagined. To open up these possibilities was indeed one of the main objectives of this paper.

IN LIEU OF CONCLUSIONS

By adopting a "general systems theory point of view" to study the operations research process, we have been able to identify its component subsystems and the links between them, considering these links as phases of the OR process. This holistic point of view allows us to see operations research in its totality and to assess the role that each of its components play.

Applying the ideas advanced in this paper to interpret the paper itself, we may say that the paper proposes a *conceptual model of the operations research activity*, and that this conceptual model has been constructed through a conceptualization process itself which used general systems theory as a frame of reference. We began from a "reality" or problem situation consisting of an appreciation of the way operations research activities are carried out. This "reality" was contrasted with a "mental system" or "experience" based on general systems theory, which organized the perceptions concerning the different aspects of OR.

This brings us back to the problem of determining what "reality" is in the context of our conceptual model of the OR process. The appreciation of a reality or problem situation is not independent from the observer or researcher. On the contrary, different OR analysts are likely to see different "realities" and react to them in varied ways. Hence the importance of the conceptualization process: through an evaluation of the conceptual models that different operations researchers develop, it may be possible to appreciate the "reality" that they see. If reality were a "fixed thing" for all, independent of the analyst, there would be no need to abstract its relevant properties and construct conceptual models.

In short, general systems theory brings a holistic perspective into the operations research process. This point of view is particularly useful for improving the ways in which the OR analyst visualizes a problem situation and develops a conceptual model for it.

ACKNOWLEDGEMENTS

This paper evolved from initial discussions with John Greiner and John Hall. Russell Ackoff made valuable comments on an earlier draft.

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