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ABSTRACT

This paper deals with the organization of two important areas which interact strongly: information science and decision-making. Both are commonly and extensively used in a variety of ways and share an equally commonly and extensively used variety of definitions. This paper deals with the mutual interaction between information science and decision-making. In order to organize or to relate these two fields to each other, a number of important criteria must be considered. For example, the organization or interrelationship should have generality, applicability, utility, reality, and the potential for quantification. A generalized information system which satisfies all of these criteria is defined in detail. It consists of four interconnected components: an information source which acquires and disseminates information (IAD), a decision-maker which accepts the information from the source and disseminates courses of action on execution function which takes the courses of action and converts them into observables (the resultant of the courses or plan of action), and a transformation function which accepts the observables and transforms them into data which are fed to the IAD. (Author)

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INFORMATION SCIENCE AS AN AID TO DECISION-MAKING

by

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Preface

This report is the result of research conducted on the relationship of decision-making to information systems. The research was supported in part by Grant GN-534.1 from the Office of Science Information Service, the National Science Foundation to the Computer and Information Science Research Center, The Ohio State University. It was administered by the Research Foundation, The Ohio State University under Project RF 2218.

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INTRODUCTION

This paper deals with the organization of two important areas which interact strongly: information science and decision-making. Both are commonly and extensively used in a variety of ways and share an equally commonly and extensively used variety of definitions. In this paper we are concerned with the mutual interaction between information science and decision making.

In order to organize or to relate these two fields to each other, a number of important criteria must be considered. For example, the organiza-tion or interrelationship should have generality, applicability, utility, reality, and the potential for quantification. A generalized information system, to be defined in detail below, satisfies all of these criteria.

Generalized Information Systems

In previous papers (12,13), we have proposed that the flow as well as the science of information is best viewed from the study of generalized information systems. Such systems are abstractions of essential components of command and control systems, management systems, documentation systems, biological and human information processing systems, etc. A generalized information system consists of four interconnected components as depicted in Figure 1.

The components are an information source which acquires and disseminates information (IAD), a decision-maker which accepts the information from the

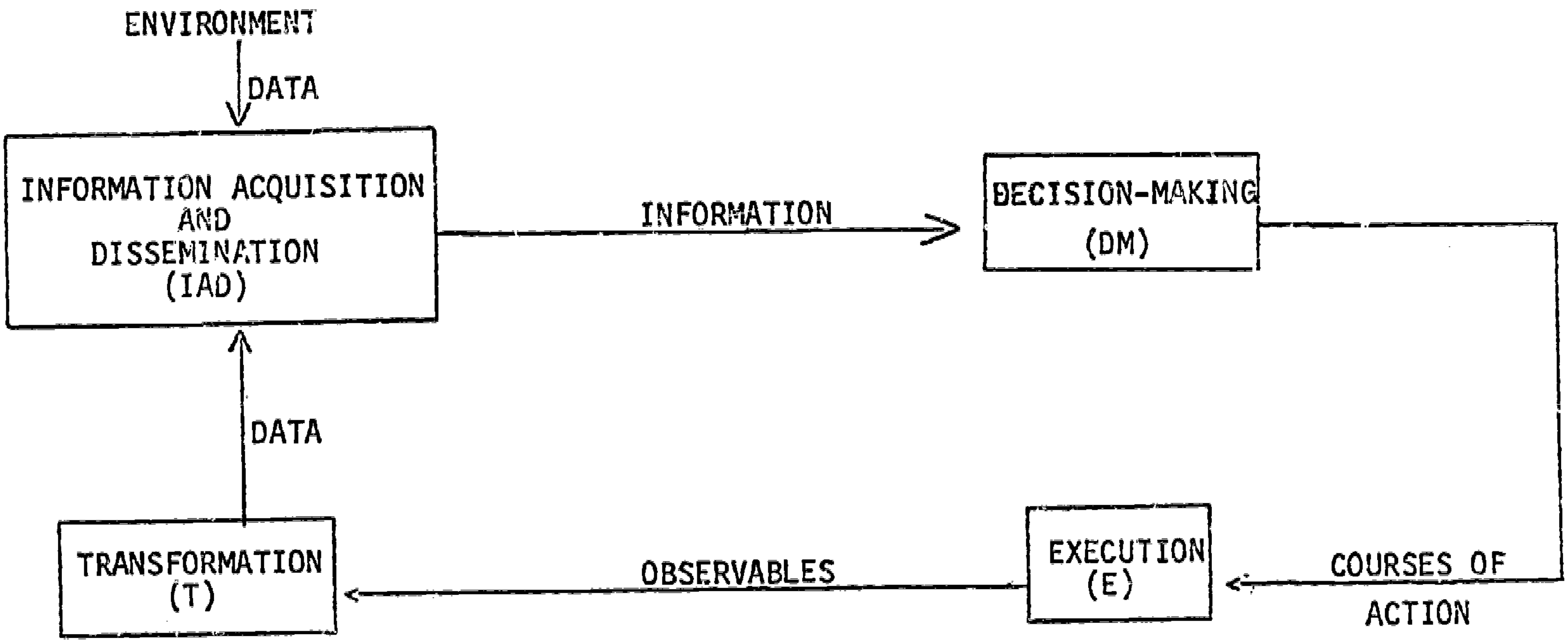


FIGURE 1. Generalized Information System

source and disseminates courses of action (DM), an execution function (E) which takes the courses of action and converts them into observables (the resultant of the courses or plan of action), a transformation function (T) which accepts the observables and transforms them into data which are fed to the IAD. Each component thus accepts and disseminates measurable quantities, is capable of performing operations on the quantities, and further has storage or memory capability. With respect to the latter, the IAD contains data obtained from the environment, from the transformation already discussed, and basic reference data; the DM stores information about the system, environment, and as will be noted later, may store information about the system operation; E stores methods of transforming courses of action to observables, and likewise T stores the conversion function of observables to data.

From this brief description it should be obvious that the generalized information system possesses the characteristics originally stated as being desirable. It is an organization which has generality, applicability, utility, reality, and is quantifiable.

In this model the decision-maker plays a dominant role. From the generalized information systems point of view, the decision-maker must satisfy the conditions of accepting, storing, and operating on information to generate courses of action (13). However, the suggestion that the decision-maker may have stored information about the environment and system operation and the fact that the decision-maker generates courses of action or plans indicates that decision-making is a central and dominant function of information systems, hence a focal point of information science. The purpose of this paper is to explore some of the implications of decision-making as a major function within information science.

Decision-Making

Decision-making has been approached from at least three distinct points of view. One approach is descriptive: it attempts to describe how a decision is made, not only in terms of the antecedent conditions, but the decision-making process, the state of the decision-maker at the time of the decision, and the consequences of the decision. Another approach is formal and prescriptive or normative in nature. This approach is exemplified by game theory (e.g., 7), statistical decision theory (e.g., 2), and Bayesian decision theory (e.g., 10). The third approach is somewhat nebulous: it implies that decision-making cannot really be understood.

The first two of these approaches are well-known. For this reason, little note will be made of them other than to point out that their impact has been substantial, particularly in management science and in the design of military command and control systems. The third, however, presents an entirely different problem for our approach.

The origin of the problem stems from the feeling that decisions may be influenced by a number of factors, many of which have no apparent bearing on the information provided. That is, for all intents and purposes, an independent observer either sees no directly relevant information or may presume that extraneous information has been used in making a decision. The former case is sometimes called a "shadow" decision. The latter is commonly referred to as an irrational decision. It usually involves political, social, or personal considerations.

Analysis of the problem posed by this approach reveals a relatively simple solution. The analysis is common among all decision-making theories and is resolved in the following way: consider the decision-maker as a black-box -- either man or machine -- receiving information, processing it, and emitting courses of action. Formally, this constitutes a mapping of the courses of action onto the input information. In this approach, this mapping is unknown or little understood. For the other two theories, the mapping is either known or may be calculated.

More formally, the decision-maker may be treated as a machine in an algebraic sense, that is, as a finite state machine. A finite state machine possesses an initial, a transitional, and terminal state (see, for example, 3). For present purposes, the initial state is the information input. There are two major sources of sets of information associated with the initial state. These are from the information source or IAD as we have termed it which includes information about the environment as sampled by the IAD, and whatever is stored in the decision-maker's memory. The terminal state is the courses of action generated. There are three major classifications of terminal states. These are (a) the courses of action either a priori adequate -- known to result in a single course of action or set of courses of action given the input state, (b) a posteriori adequate -- found to result in a single course of action or set of courses of action or set of courses of action after the process of decision-making has taken place (c) or indeterminate, that is, no singular mapping may be found.

To better illustrate the nature of the terminal states, Figure 2 shows a typical form of each given a known or fixed information input state. In this figure, an arbitrary information input of four states (I_i, i=1, ..., 4), an arbitrary set of four possible courses of action (A_j, j=1, ...,4),

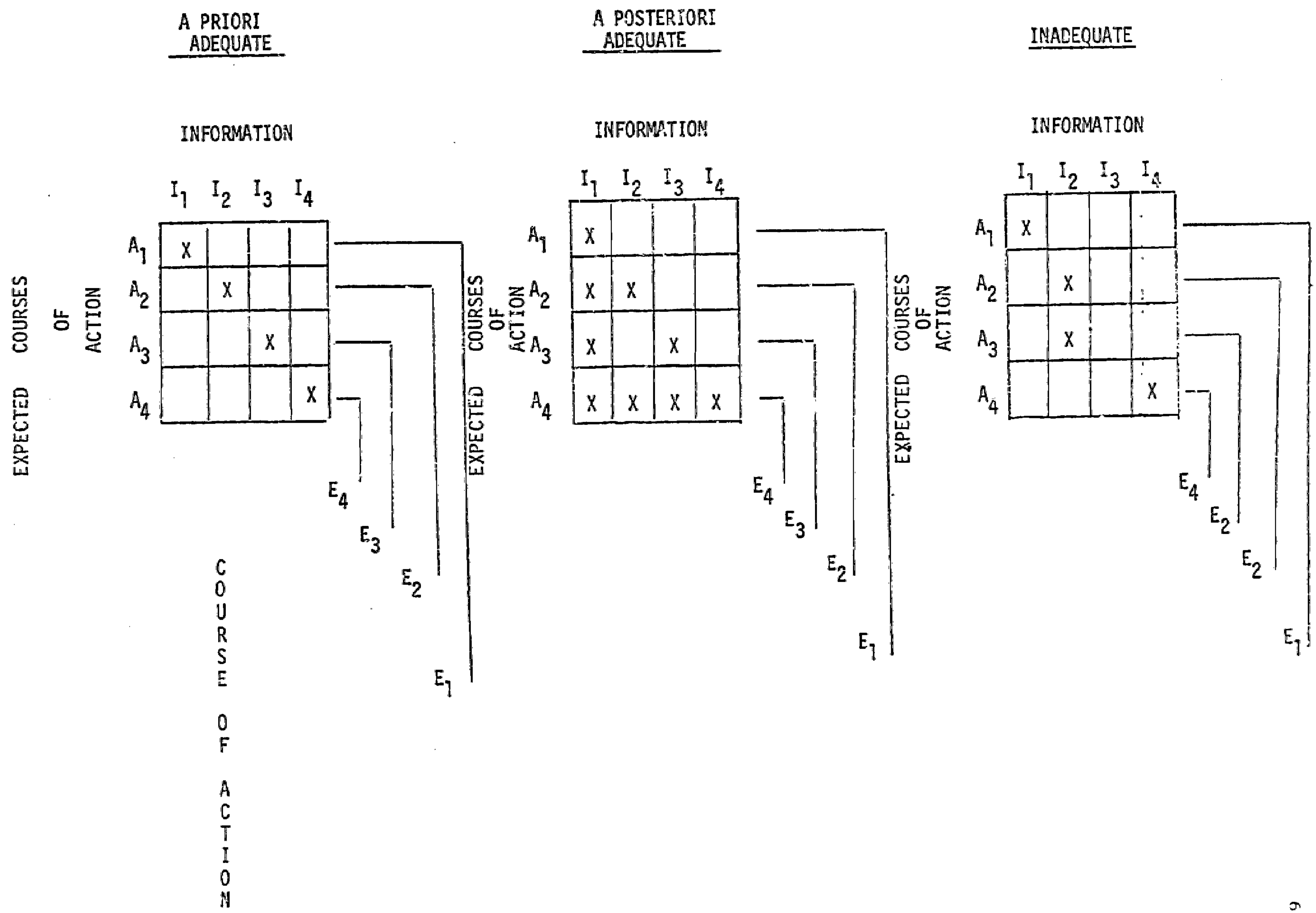


Figure 2. Examples of Decision Matrices.

and four unique terminal states (E_k, $k=1,\ldots,4$) representing the input to the E function are used. The figure shows how (by noting whether or not the rows or columns are uniquely filled) the initial state I progresses through the transitional state A to the terminal state E and whether or not E is unique.

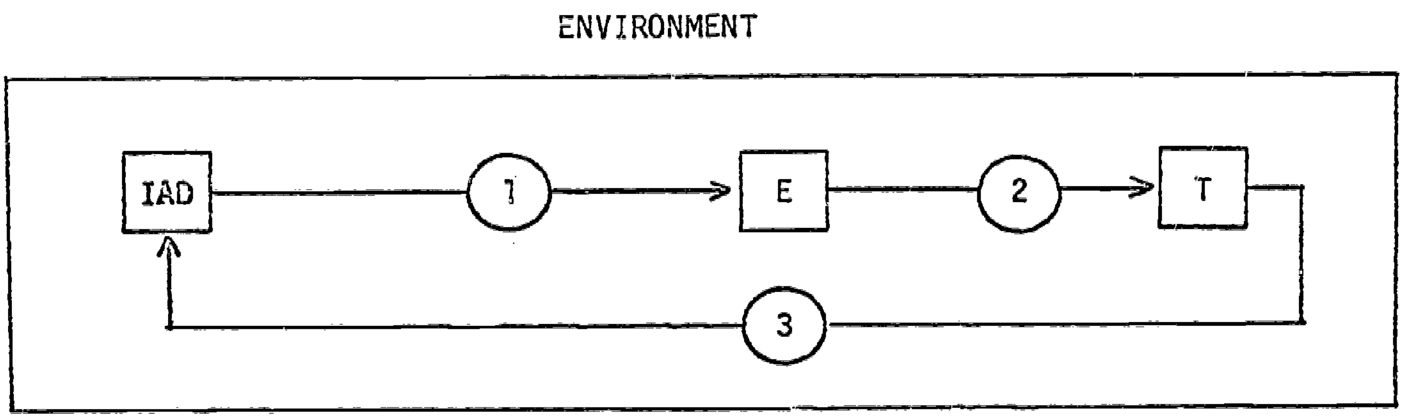
The purpose of this discussion is to clarify the nature of a decision. In summary, there are relatively few distinct states that exist in decision-making. Moreover, this discussion also suggests ways of making decisions within the context of the general model proposed at the outset of the paper. That is, how can the decision-maker utilize information from the IAD and select courses of action? The abstract structure provides a means for handling this and related questions.

All of the initial and terminal states of the model, with the exception of one, have been defined. The exception consists of what may be stored in the decision-maker's memory. One possibility includes prior experience (political, economical, social, historical, etc.) related to the decision-maker's frame of reference. Another includes his knowledge of system operation. The latter case is treated in detail, mainly because it may be formalized more rigorously than the former. Essentially, we are proposing that the decision-maker has knowledge of system operation, how the system should operate, and what should constitute "good" system operation. While this may be experiential to a large extent, many of the aspects of the decision-maker's knowledge of system operation have been or are capable of being identified.

The point is that the decision-maker must have some overall model of the performance of the total system which results in the generation of some set of observable actions. This model need not be -- and for more complex situations will probably not be -- an analytical or even explicable model. It need not even be a rational model. It is a frame of reference that the decision-maker uses to relate the information to which he has access, to some set of observables. As indicated, this model will probably be heavily influenced by the background, experience, and outlook of the decision-maker. Indeed, when it is sometimes said that a particular type of decision-making is an art, it is meant that the model can be learned only by experience and cannot be described in analytical terms. "Common Sense" would also fall into this category.

When additional information is received by the decision-maker, he then establishes some courses of action which will result in observable actions. Information about these observables is eventually fed back to the decision-maker so that he can decide whether his model and his decisions were accurate and satisfactory. If the information fed back is not the expected information, then the decision-maker can either change his decisions, resulting in new courses of action or he can change his model of the process. These ideas are developed in detail in references (12) and (13).

Knowledge of system operation, including environmental factors, may be represented as in Figure 3. In this figure, the decision-making function is represented as the IAD, E, and T functions, each of which, rather than a real entity as in the generalized model, are perceived or inferred characteristics of system function. The flow, indicated by the numbers 1, 2, and 3, constitute the mapping of A onto I, anticipated observable actions, and anticipated data respectively. That is, it is assumed that the decision-maker is aware of and effectively uses characteristics of the environment



1 Information

2 Courses of Action

3 Data

Figure 3 Representation of Stored Informatioı. in Decision-Making Model.

of the system, and that he has knowledge of environmental factors influencing his own behavior. In the same sense, it is futher assumed that he has knowledge of the operation of the IAD -- how it collects, stores, disseminates information, and how data from T are returned to it and processed through it -- and of pertinent sources of perturbation. The same is held for the other functions -- namely E and T. It is assumed that the decision-maker infers how execution is accomplished, what the necessary inputs and probably outputs are, and what factors influence the E function. For T, both observables and data are presumed known as is the processing function and environmental inputs. Quite generally, this is a delineation of what is held in store in the DM, with the additional qualification that the decision-maker may have knowledge of what perturbs or influences his decision and how this influence occurs.

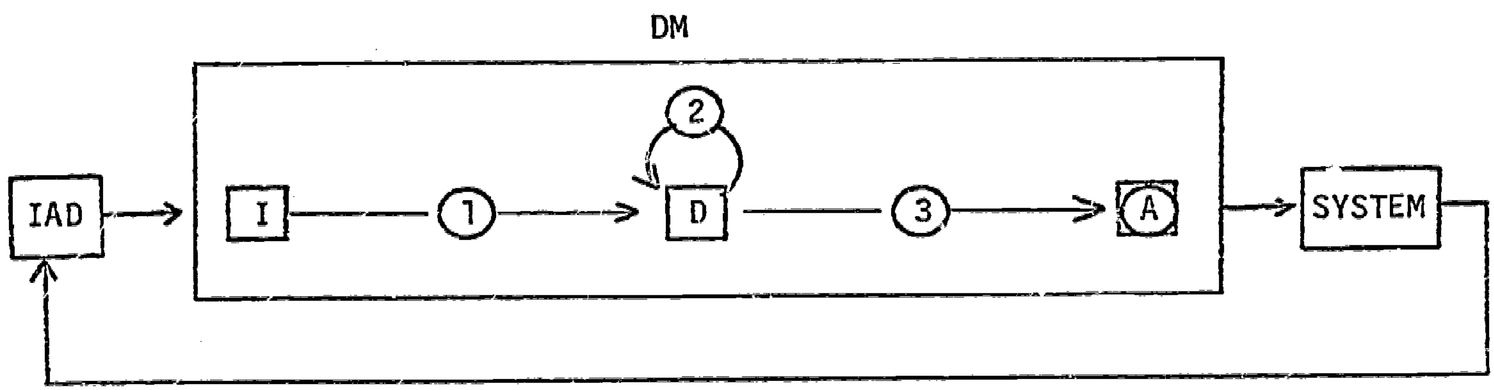
Knowledge of this kind is frequently referred to as "know how", "executive capability", or simply a description of the model of system operation. The internalization of the system is superficially similar to a concept proposed by Churchman (4). This concept is of a world view or Weltanschauung held by the decision-maker relative to the system he is regulating or managing. Our point of view differs to the extent that the world view is a structure internal to the decision-maker, hence part of his processing capability.

From our point of view, the primary function of the decision-maker is to establish that mapping of information into courses of action which best regulate the system given the constraints of the system already delineated. Since this may be accomplished in a variety of ways depending upon the system constraints, further formalization is profitable. The formalization is realized by returning to the model of the decision-maker as a finite state machine. The underlying assumptions, namely initial, transitional, and terminal states along with several instances of each have already been given. The present discussion is limited to these instances and, in a sense, is a recasting of the problem.

For the recasting, consider the decision-making subsystem outlined in Figure 4. This subsystem consists of the IAD feeding information as the subsystem input. The subsystem output is courses of action to E and T as a combined subsystem. Within this subsystem, the principal components are I, the information input set, D, the decision which includes the internalized total systems model as stored information, and A, the courses of action generated. The behavior of the subsystem is governed by the I, D, and A functions, and these transformations within the subsystem. These transformations may be represented in detail by the arrow-associated numbers 1, 2, and 3, in Figure 4.

Number 1 represents the link of the perceived information to the decision-maker. Number 2 indicates stored information within the decision function. This information can be compared with the input set of information. The result of this comparison is a set of projected courses of action designated by number 3.

Each of these states and their transitions should be thought of in terms of expected values, that is, as anticipated events or occurrences. In this respect they are "hypothetical." Given an information set, however, they are fully capable of being estimated.



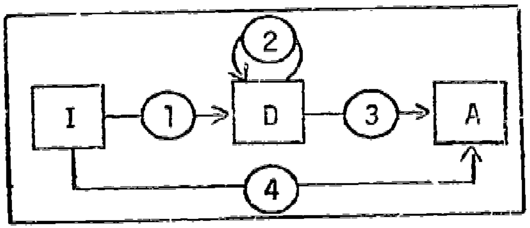
1 Perceived Input Information
2 Stored Information
3 Mapping Function

Figure 4 Decision-Making Subsystem.

The flow and possible routes of flow, denoted by the arrows, generate a number of models of decision-making. For illustrative purposes, four possible types of models are shown in Figure 5.

The model at the tope of the figure represents decision-making where there is little a priori uncertainty regarding the execution of a decision and its influence on system behavior. Each component and numbered arrow flow are identical to that of Figure 4 except that an additional flow, designated by the number 4 is included. This represents the case of a fixed and known decision for one set of input information. This model is appropriate for decision-making systems for which specific, well-understood, unique courses of action are associated with each set of input information. It is analogous to the a priori adequate class of terminal states.

The second model shown is exceedingly more complex. In addition to the components and flow of Figure 4, A feeds back the expected action to the information input for a check on its suitability. (This is indicated by number 4 in the diagram.) In such a situation multiple courses of action which may be generated are considered and the resulting output data are compared with the input information. Thus, a best course of action may be decided upon through further processing. From the comparison, the information must again be inputted to D through 5. This input is a modified information input. A new mapping function indicated by number 6 is produced. This model arises from the necessity of the decision-maker to compare the results or anticipated results of his decision with the original information. In order for courses of action to be generated, the original input information must be revised, re-inputted, and remapped. The model is analogous



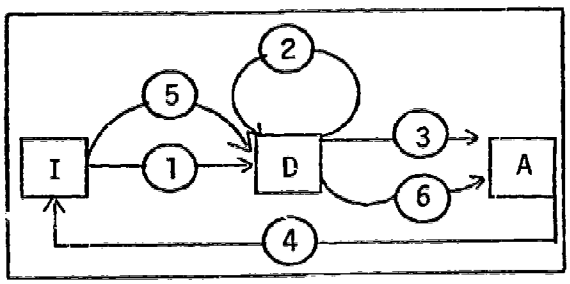
1 Perceived Input Information

2 Stored Information

3 Mapping Function

4 A Priori Mapping Function

Model 1



1 Perceived Input Information

2 Stored Information

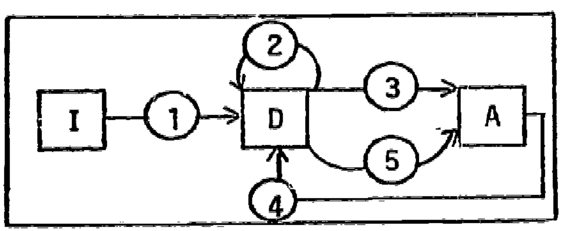
3 Mapping Function

4 Anticipated Course of Action Feedback

5 Information Revision

6 Mapping Revision

Model 2



1 Perceived Input Information

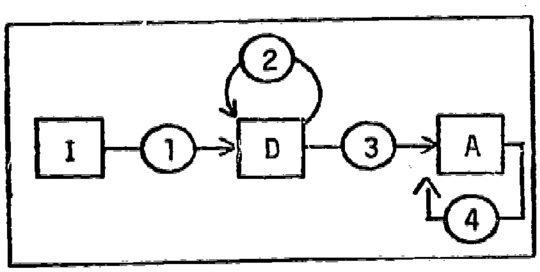
2 Stored Information

3 Mapping Function

4 Anticipated Course of Action Feedback

5 Mapping Revision

Model 3



1 Perceived Input Information

2 Stored Information

3 Mapping Function

4 Anticipated Course of Action Feedback

Model 4

Figure 5. Four Models of Decision-Making Subsystems.

to one of the a posteriori adequate class; the feedback is required to obtain proper system activity.

A special case of this model is given in the third example. For this model, feedback to D takes place through number 4, and a new mapping function to A through 5 is generated. This model revises a decision on the basis of expected outcomes of courses of action. It is the widely known Bayesian model.

Finally, the fourth example indicates a decision model of a form such that no singular course of action or consistent set of courses of action may be made. This model indicates a situation in which two distinct sets of information and courses of action could result in the same execution or an execution irrelevant to the information. While this could imply that the information or courses of action were equivalent or redundant, it could also imply that the mapping function could not lead to a unique terminal state A. Such a model could arise under a variety of circumstances. The fourth model represented in Figure 5 illustrates an anticipated course of action that loops back on itself through number 4. The loop obviously could lead to an inconsistent set of courses of action transmitted to the E function, a reserved decision, or no decision at all.

As previously noted, with these simple considerations, many models of decision-making could be constructed. They could differ not only in structure and flow but in content. The formal structure, however, is highly significant in that it provides the basic features of decision-making. Moreover, when applied to an actual decision-making situation, the structure is quantifiable. Criterion measures -- times, errors, and probabilities, for example -- could be substituted for any of the numbered transitions in the flow diagrams. Finally, it should be pointed out that the emphasis throughout has been on anticipation. That is, how does the decision-maker expect his decision to be processed?

Information and Decision-Making Aids

We have now established a close relationship between information and decision-making by establishing the role of decision-making within generalized information systems. However, we have spoken of information loosely. At this point it is important to establish a rigorous definition of information.

Information has many distinct meanings. One meaning involves the exchange of a communication with linguistic or semantic content (e.g., 1). Another meaning is quantitative, involving the measurement of numbers of available choices (e.g., 11) or precision of measurement (e.g., 5,6). Yet another meaning refers to printed matter, verbal communications, visual communications, and similar kinds of sources.

Within a generalized framework, each is too restrictive to provide the necessary criteria, utility, and analytical expressions for application to realistic situations, such as may be treated by information science. For this reason, we have chosen to define information as "data of value in decision-making". The definition is not new, having been proposed earlier by McDonough and Garrett (8). Moreover, Payne (9) has extended the notion by suggesting that the value and use of information is the principal factor for the existence of information systems. The point to be stressed is that information is not raw data or isolated facts but a structure which can be used by the decision-maker in regulating the system. The structure is obviously dependent not only on the particular system, but on the decision-maker. To this extent, information is highly "context sensitive."

Context sensitivity is in part system and environment dependent and in part decision-maker dependent. The extent of context sensitivity can be illustrated by considering what is required of operating information systems.

Operating information systems should have several desirable informational characteristics. A partial listing of such characteristics includes accuracy, relevance, timeliness, sufficiency, lack of bias, and adequacy. Accuracy refers to the "truthfulness" or fidelity of the information. Relevance refers to the bearing the information has on the control or regulation of the system. Timeliness refers to the time of the arrival of the information. Sufficiency is concerned with whether or not the content of the information, though accurate, has distortion. Adequacy refers to the amounts of information which the decision-maker needs; typically he receives too little or too much.

If these criteria are not met, the difficulty of making a decision is compounded greatly. Generally, the decision-maker is forced into a situation of relying on his own judgment or stored information, attempting to make a good guess, delaying his decision, or reserving his decision entirely. From a systems point of view, information generated under these conditions has little value. The consequences for system operation could easily be catastrophic. This follows not only from the desirability of the characteristics but from casual observation. Yet, somehow the system usually seems to survive.

We believe that the model we have proposed suggests not only ways in which these criteria may be achieved, but also how in their absence, the system continues to function. For the former, the issue is resolved by system design. For the latter, the issue is resolved by systems analysis.

A partial solution can be found within our model by considering what is contained within the information acquisition/dissemination function, the decision-making function, and the interface of the two. Initially, because we have defined information as data of value in decision-making, the IAD must contain data which in part satisfy the criteria listed. Such data may be viewed as a set of elements generally, although in fact the precise content will depend on the system itself. The elements of the data set must be capable of being structured. It is the structuring which exerts a profound influence over decision-making. The form of the data elements is not of great importance: they may be independent, dependent, or by some rule, implicative of some other element. The structure may either be contained in the data set or inferred from the set by the decision-maker.

Inferences by the decision-maker regarding the processing of the information may be made. The types of inference possible we have previously identified as conservation, reduction, or translation (13). In conservation, the decision-maker preserves the information content as his information input. In reduction, the decision-maker reduces the set of data as his informative input. In translation, he changes the form or the structure of the data as his informative input. The interface, then, must be capable of transmitting the information. Because passive dissemination of information is not likely to possess the degree of desirability of any of the criteria mentioned, it may be more fruitful to allow an interrogative or interactive interface in which the decision-maker may ask questions of his data base.

Reconsideration of the models of decision-making developed in this paper reveals some of the motivation for their application. The models were anticipatory in the sense that the decision-maker was assumed to be expecting the system to behave in a certain way. System feedback, then, is important in the sense that the decision-maker needs to compare the output of the system with his own expectations. It was also for this reason that the models were developed as internalizations of the system. From a systems design point of view, the Information Acquisition/Dissemination function should contain data highly relevant to the decision-maker's needs. He may then, by appropriate interrogation, obtain information about the system behavior before executing a course of action by examining the likely system outputs. Moreover, the actual feedback provides him with a check on both the accuracy and the adequacy of his model or mapping function.

We believe that this systems approach is not only fruitful for the future design of information systems but for the understanding of information science. Information science is the study of information systems of this general form. Information systems may be dichotomized as artificial or natural, depending upon whether or not they were constructed by man.

It is also possible to have mixed systems, resulting either from the evolution of an artificial system to a system containing natural properties, or the evolution of a natural system to a system containing artificial properties.

The criticality of the decision-making function in information systems has been shown. The future or fruitfulness of our approach remains to be seen, since it relies heavily on the application and potential modification of the generalized information systems model to specific information systems.

For decision-making aids, the implications are fairly straightforward. The information contained within the source must serve the needs and uses of the decision-maker. To a large extent, it must be capable of responding to intelligent questions asked of it, particularly when the initial set of information is not sufficient to provide the decision-maker with a potential set of courses of action. Thus the source should be interactive with the decision-maker in some degree. Because the information must serve the needs and uses of the decision-maker, it must naturally be system relevant. Without relevance, execution and transformation are impossible. Finally, the entire system, defined by its components, must provide feedback to the decision-maker. It is only in this way that the decision-maker can evaluate the adequacy of his model and subsequent actions. We have indicated that this closure is through the Information Acquisition/Dissemination function. In the absence of the closure, the decision-maker remains in a state of uncertainty. To aid him in the reduction of his uncertainty, feedback through his source is obviously required.

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