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ABSTRACT

In this paper the roles and functions of man in the evolution and development of two complex specific systems within the Army operational environment are discussed. It is pointed out that throughout the course of historical development, the basic system functions and objectives have remained unchanged even though the system equipments have varied. With equipment changes, man's physical functions in system operation have also changed. In predicting the effectiveness of man in a future system operational environment, an approach independent of equipment differences is required. Such an approach in which man is conceived as an information processor is described. The approach is applied to the human operator roles in manned aerial reconnaissance and surveillance and in targer acquisition. (Author)

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A View of Man's Role and Function in a Complex System

by

Francis H. Thomas

Presentation at the
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Prefatory Note

This paper was presented at the 1968 annual meeting of the Alabama Psychological Association held in Birmingham, Alabama, May 1968. The paper represents an application of current research on information processing conducted by Division No. 6 (Aviation) of the Human Resources Research Office, under Exploratory Study 61, Reconnaissance and Surveillance.

A VIEW OF MAN'S ROLE AND FUNCTION IN A COMPLEX SYSTEM

Francis H. Thomas

The role and function of man in a complex system is without question the key to effective system operation. Whether he is the system planner, the system operator, or the system user, man tends to intrude somewhere in the system process. Even in those instances where fully automatic systems are employed, as in the refinement of crude petroleum products or in the manufacturing assembly line, man enters into the system process when he devises the system or makes use of the product it produces. And frequently he is even involved in automatic system operation, although not as an active participant, when he surreptitiously peers at dials and gauges to monitor and report on the system status. Thus, we have two major components, man and machine, functioning together to provide a particular product or service.

It may be that the systems concept is being much overworked today. We hear institutions and organizations, and even games, that we have long accepted at face value called "systems" (1). However, the use of the term does have some merit. It provides a framework within which to examine more closely the underlying purposes of the institutions and organizations we have tacitly accepted on an intuitive basis. If only for this reason, there is justification for considering systems that have long been accepted as part of our way of life on a more analytical basis.

Systems have, or should have, purposeful behavior—that is, they are goal directed. Take for example a very simple system one may see, or one used to see, at any rate, on a small construction job—a man pushing a wheelbarrow. The barrow is the hardware component while the other component—man—serves the role of a guidance and motive force to transport material from point A to point B. The input, what the barrow receives, may be obtained from another system—perhaps a mixer combining sand, water, and cement to provide the concrete used at different places in the construction job. Here we see some simple type systems, one system to process raw materials, the other to deliver a load from point A to point B.

However, man, because he is often more flexible than his companion hardware component, may divert the system from its intended purpose. The simple example of the man and the wheelbarrow we have used will illustrate the point. You may have heard the story of the worker in a highly classified atomic energy plant. Several times a week this worker, at the end of the work shift, would come trundling up to the plant gate pushing a wheelbarrow covered with a cloth. The guard would dutifully throw back the cloth and inspect the contents. Invariably he found a lunch bucket, which he examined, and sometimes a couple of dirty towels. This procedure went on for some time with the guard becoming more perverse in his behavior—probing the tubular handles, taking off and examining the tire, and subjecting the wheelbarrow to a thorough examination. One day the guard finally exploded, "I know you are stealing something; what is it?" As the worker took off at high speed he shouted, "Wheelbarrows!" In this case, man's role changed from that of being a participant in a delivery system to one of active engagement in a barter system.

A system, in addition to the goal-directed behavior of its components, has a more or less definable structure and certain specifiable functions. There are linkages among components and levels of organization which bind the system together into a complete entity. Moreover, there are internal processes at work to provide the vitality to what would otherwise be a conglomerate of diverse elements. It is to this latter characteristic of systems—that is, the functional context—that this paper is addressed.

For the last two decades, during World War II and thereafter, the military services have utilized the system concept to more effectively implement their respective missions. The impetus to the acceptance of the concept was provided in large measure by the U.S. Air Force in its concern to make new weapon delivery systems more effective. This fact of life is readily understandable when one considers the relative simplicity with which a delivery system may be analyzed. Basically, it is much the same as our earlier example of the worker pushing his wheelbarrow from point A to point B to dump his load of concrete. However, the U.S. Navy and U.S. Army were not far behind in their recognition and application of the concept. In an article by Marvin Kalb in *Saturday Review* (2), the CBS Washington correspondent points out the successful manner in which the systems approach has been applied to that amorphous structure called the Joint Chiefs of Staff who oversee the entire military establishment.

The system concept, while generally applied to the planning of new systems, can be utilized in the analysis of systems with a long historical development. One of the beneficial features of the concept in new system planning is that the system goals can be set forth in a parsimonious manner. As one multiplies the system objectives, there is the problem in trade-offs, and each of the several goals may be sub-optimized as a consequence. When one analyzes historically developed systems, the likelihood of the presence of multiple goals to which differential weights must be applied becomes more evident.

As a basis for comparison and discussion, two systems which have been long employed in land warfare will be considered. These systems fall in the two categories mentioned earlier—one categorized by its processing function, the other by its delivery function. Representatives of the latter is what we call a Fire Power System—its purpose is to neutralize or destroy a target. An example of the former category is the Combat Intelligence System—its purpose is to convert raw data into battlefield information and intelligence.

These two systems have their roots far back in the history of man. Our early ancestor functioned in the context of a Fire Power System when he delivered a blow with a rock or club, with spear, arrow, or catapult. These weapons were the components of an incipient system with man playing the key role in the delivery of the missile to its destination. These are the tangible aspects of a system-in-being.

Not so tangible are the system-like activities that preceded the delivered blow. About these we can only speculate. It seems reasonable that in a potentially hostile surrounding, man searched for signs and indications of a hostile presence—that he attempted to assess the situation from information available in his surrounding environment. In essence, early man served in a dual capacity—as an information processing system, and as a fire power system.

While the modern counterpart of these two embryonic systems has greatly changed in appearance, the basic functions in their operation remain relatively the same. In the Combat Intelligence System, the basic functions are information collection, information processing, and the dissemination of information and intelligence. The functions of a Fire Power System are target acquisition, target engagement, damage assessment, and dissemination of the results. Of the various functions required of both systems, we will be concerned with only the initial phase of each system for comparative purposes.

At the first operation phase of the Combat Intelligence System, information collection is achieved through a number of different agencies, both ground and air, and from a variety of sources. Agencies, for example, would include manned and unmanned aerial reconnaissance and surveillance aircraft or ground patrols and ground radar sites. Information sources, to illustrate the distinction between agencies and sources, might include prisoners-of-war and captured enemy documents.

Target acquisition in the Fire Power System is provided by two main sources, outputs from the Combat Intelligence System or from within the Fire Power System itself. In actuality, the Fire Power System is composed of a hierarchy of different weapon systems, each with its own capability to acquire targets. The most rudimentary of these is the combat infantryman and his rifle—and these systems range up to the most advanced nuclear weapons. In the hierarchy of weapon systems, target acquisition has a different connotation for each system. What would be considered an appropriate target for a single rifleman would not, obviously, be appropriate for a nuclear device. On more than one occasion we have seen systems fail to fulfill their purposes because system developers failed to give the necessary attention to means for the system to acquire targets appropriate to its weapons. A target, then, is an object on the battlefield that has reference to the lethality and range of a specific weapon system.

Target acquisition within the Fire Power System is achieved by components similar to those employed in the collection of information by the Combat Intelligence System. In some instances, this similarity would appear to be an unnecessary duplication of limited resources, both of men and material. However, because of the differences in system requirements each system can operate more effectively when the integrity of the system components remains intact. Furthermore, the time frame within which the two systems must function is of a different order of magnitude. The Fire Power System by its very nature tends to operate in the "here and now," while the Combat Intelligence System must look to the future and anticipate the course of enemy action.

A major difference between the two systems which deserves more consideration than it has received in the past, concerns the roles and functions man must assume during systems operation. To illustrate the point we will consider the airborne subsystems in each of the two major systems.

Looking at the roles and functions of man in the initial phase of each system, we find that the roles are identical but the functions differ. In the collection of information by manned aerial reconnaissance and surveillance aircraft the roles assumed by man may be classified into three major types. The first role is that of man serving as a primary sensor, as in direct aerial observation. The second type is that of the vehicle controller, who is primarily responsible for directing the aerial vehicle from point of origin to destination and return. The third role is that of inflight sensor operator in which man serves as a secondary sensor. The sensor aboard the aircraft may be radar, infrared photography, or remote television. All are assumed to be presented on displays available for inflight inspection by the sensor operator. These three roles may be performed by one, two, or three individuals, or one role may be shared by different individuals. In the target acquisition aircraft we find similar equipment and the same roles, that is, man as a primary sensor, as secondary sensor, and as vehicle controller.

Because of the similarities in roles and equipment it has been tacitly assumed that man as a similar component can be interchanged between systems. After all, as noted, historically man has been capable of carrying out multiple roles not only in warfare but in his everyday living. But the question we raise is not whether he *can* perform certain roles, but whether he can perform them *effectively*. To consider this question further, let us examine some notions that have been set forth as to the manner in which he might function.

Throughout the history of psychology various approaches have been conceived as to the manner in which man carries on commerce with his external environment. One such approach which has been developing over the past several years finds its roots in computer technology and communication theory. Statements of this approach have been provided by McCormick (3), Broadbent (4), Gagné (5) Mandler *et al.* (6), and Melton (7). This approach conceives man as a processor of information obtained from the external environment. The notions on which information processing theories are based seem particularly appropriate to the human behaviors involved in aerial reconnaissance and surveillance and in target acquisition.

McCormick (3) describes the basic form of human information processing, involving three in-line stages—information receiving, information processing and decision, and an action stage which includes physical control and communication, as shown in Figure 1. A fourth stage, information storage, interacts with the in-line stages to aid in transforming information input to some form of output.

Information Processing System

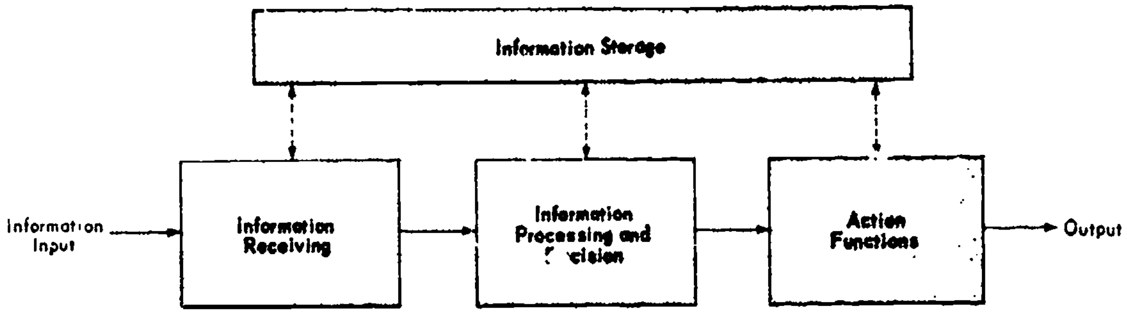

Figure 1

According to the particular theoretical interest in a specific stage, different mechanisms have been proposed by the theorizers as to the manner in which an information input is transformed to an output. In general, information processing theorists, such as Melton (7) and Egeth (8), are concerned primarily with the selective processes in behavior, for example, vigilance, visual search, selective listening, choice reaction, and decision making. These areas have a high degree of relevance to the performance of intellectual and perceptual-motor skills in manned aerial reconnaissance and surveillance and in target acquisition.

We have modified the simpler information processing model described by McCormick (3) to include mechanisms emphasized by others in accounting for the transformation of information from input to output, as shown in Figure 2. At the receiving stage, information is picked up from the external environment by way of the various perceptual systems; the importance of these systems is emphasized by Gibson (9). Each of the five perceptual systems has its own mode of selection (peripheral attention) by which it reduces the amount of information registered from the external environment.

According to this view, emphasis is on functional rather than anatomical relationships. For example, the visual perceptual system includes not only the organ of sight and its associated neural structure, but also the muscle structure for turning the head in the process of looking at some aspect of the environment. Information as such at this level is considered not to require any processing since the mobile organism in its daily contact with its environment (which is continuously changing in perspective and transformation) registers the changes and non-changes in stimulation which are invariant to specific objects and events. At the information-receiving stage, the more usual descriptions of the functions involved are those of detection and recognition, which can be expressed by "I see something (of interest),"—detection, and "It appears familiar,"—recognition. The opposite of recognition, novelty, is accounted for by Gibson (10) in this view: Where recognition is expressed as "same as before," novelty is simply the alternative "different from before."

Tentative Synthesis of Information Processing Functions

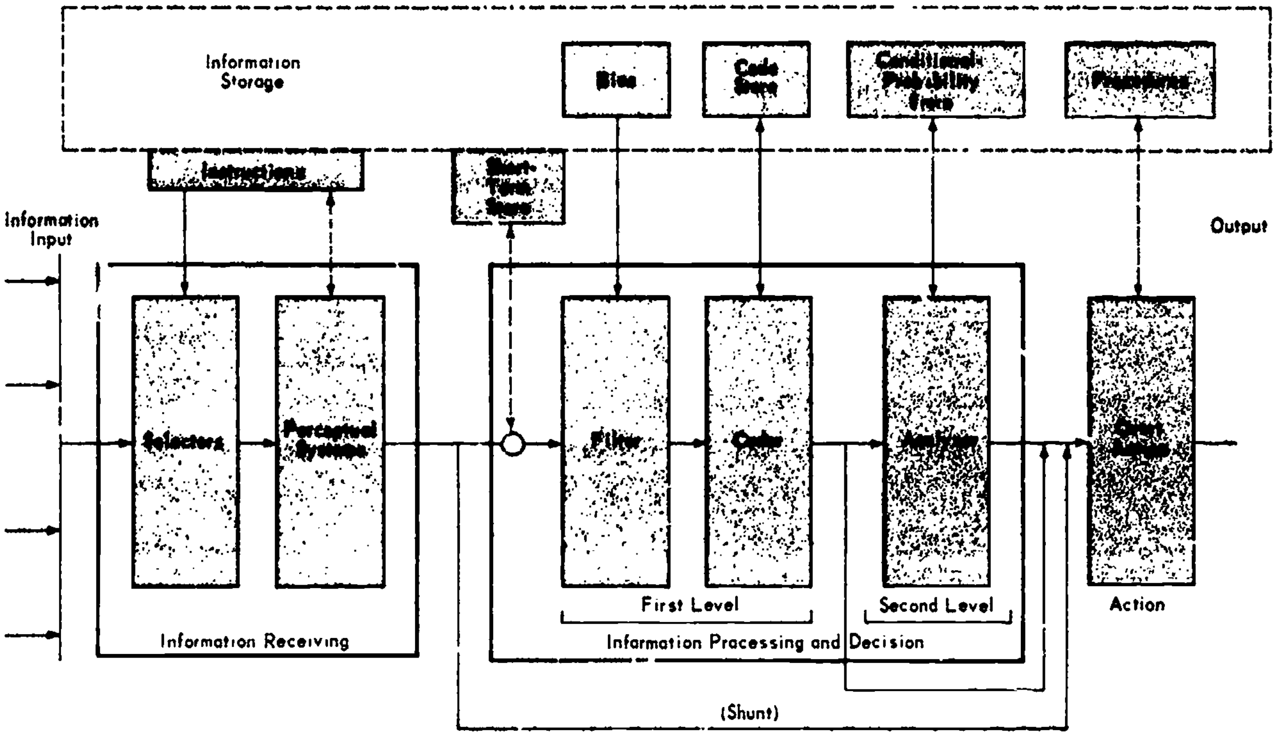

Figure 2

Information processing, which is emphasized by theorists such as Bruner (11) and Smith (12), is the next stage in the sequence and appears to include two different levels of processing. At the first level two mechanisms are suggested as a means to adjust the rate at which information is accepted for processing. Of these, the first seems capable of holding back or storing information for very brief periods of time. This short-term storage function is described by Melton (13, 14). The second mechanism, described by Broadbent (4), Moray (15), and Treisman (16), modulates the rate of flow. This latter mechanism acts as a filter with a variable bias. A distinction is made here between the selector at information receiving and the filter in information processing as different forms of attention. The former is viewed by Gibson (9) as peripheral attention, whereas the latter is likened to a form of central attention.

The major function at the first level of information processing is stated by Bruner (11) to be one of categorizing the information input. This function requires the act of grouping and coding incoming information, where the coding process involves the use of memory storage. The more usual description of this stage of information is included in the term "identification," that is, "naming."

At a second level in the processing sequence, a much greater reliance is placed on the contents of information storage, for it is at this level that the information input is analyzed on the basis of the organism's past experience with the objects and events. In effect, the analyzer operates not on the processed information as such, but rather on the information that is lacking after initial processing—that information which should be present from past experience.

Additional information may be acquired by action-directed search of the external environment or from information storage. If active search does not fill the information gap, the analyzer initiates a series of "if-then" relationships based on conditional probabilities available from storage, that is, "What goes with what," or "Given this (processed information), this should follow (the information needed to fill the void)." This process is described by a variety of terms, for example, guesses, hypothesis-using, inferences. The term selected here is interpretation.

The final stage in information processing is one of overt action. This stage itself provides information input. One's own actions are observable events which of themselves are available as inputs (e.g., by way of the visual and auditory perceptual systems). Not all information received by the organism requires processing to result in some form of action. The processing stage can be shunted out entirely (as in well-practiced motor skills) or the process can proceed to the identification level and the interpretation function shunted out (as in naming objects and events). Gagné (5) provides a description of this shunting mechanism.

The four main constructs in the information processing model, that is, selector, filter, coder, and analyzer, have been utilized (though not necessarily in these terms) by a variety of researchers in the field of human information processing. The model outlined here attempts to synthesize the sometimes divergent theoretical views in an effort to create a broad outline or taxonomy appropriate for the analysis of crew-member activities in manned aerial reconnaissance and surveillance and in target acquisition.

Let us now consider these functions in relation to the role of man as a sensor, either primary or secondary, in manned aerial reconnaissance and surveillance and in target acquisition. What we will examine is the role of man in the information collection stage of the Combat Intelligence System (the Combat Intelligence Man) and the target acquisition of the Fire Power System (the Target Acquisition Man). In Figure 2 on page 6 five loci are shown at which functional differences may arise—in the blocks labelled instructions, short-term store, bias, code store, and conditional-probability store.

Instructions from a previous information input, retained in information storage, influence the selector pickup and may or may not affect the perceptual system output. Self-generated instruction, not necessarily arising from information storage, will tend to operate upon the selector and the perceptual system output in a similar manner.

In the real world situation we have been considering, different kinds of terrestrial information would be selected by the Combat Intelligence Man (i.e., the operator in the intelligence system) and the Target Acquisition Man. If a heavily wooded area appeared in the display (either the real world or sensor) the Combat Intelligence Man would search for breaks in the foliage in an effort to sight indications of enemy activity. If the instructions to the Target Acquisition Man given during the preflight briefing had indicated the presence of enemy tanks, he would tend to disregard the heavily wooded area and search elsewhere. Since the Target Acquisition Man's instructions include the anticipatory statement that enemy tanks are present, he is more prone to perceive input information as "the presence of tanks" than is the Combat Intelligence Man.

A difference also occurs at the first stage of processing in short-term memory store. Where the Target Acquisition Man is actively searching for information inputs that constitute a unitary event, the Combat Intelligence Man is constantly receiving inputs at a high rate that must be continuously processed. Thus, the rapid sequential presentation of environmental information requires that some of the available input be restrained for a brief period in short-term store.

The three other mechanisms, that is, the bias on the filter, the code store, and the conditional-probability store, represent resultants of past experience and training. These mechanisms all exert varying degrees of influence on the information processing functions of our two hypothetical men. Due to the different kinds of training the two men receive, they will attend to, or the filter will pass, different inputs for processing as a consequence of the stored bias. For the Combat Intelligence Man negative information for the intelligence system in which he operates—that is, there is no change in enemy status—will be a focal point of attention. For the Target Acquisition Man, the lack of change may not even be apprehended.

In code store the names and groupings applied to environmental information may be the same for each man, but the generic specification of the input will be categorized by one as a target, by the other as "new information."

At the final stage of information processing, the difference in the processing activity of our two hypothetical characters is one of degree rather than kind. The stored conditional-probabilities of the Combat Intelligence Man cover a much wider range of contingencies than those of the Target Acquisition Man. In the process of collecting accurate information, the Combat Intelligence Man may go through several iterations to produce an output which in turn becomes an input to the system of which it is part. In the early period of his information acquisition from the specific environmental source, the information inputs may be quite fragmentary and may require that a series of "if-then" relationships be initiated. On the other hand, the relatively limited inputs that are categorized as enemy tanks place less of a requirement for analysis by the Target Acquisition Man.

The hypothetical illustration I have used was intended to point out that the analysis of complex situations involves more than a description of system components and the part these components (particularly man) play in system operation. There is a need to understand and to predict how a component, such as man, will function in some future operational system. While the characteristics of hardware components included in future systems may change, two features that seem to be invariant are (a) the basic functions and objectives of the specific system, and (b) the information processing characteristics of man. From these two invariant features one should be able to predict man's relationship to future systems.

I have been describing a model of man's functions as a processor of information. This model has been developed as a means of better assessing man's functions and roles in aerial reconnaissance and surveillance systems in the hope of improving our predictions of the comparative effectiveness of future systems. The dollars and cents consequences of improving such predictions are enormous, and man, while being the most flexible and variable component of these systems, has received the least systematic study. We plan to pursue our model experimentally; we are hoping to develop parametric indices describing human performance in aerial reconnaissance and surveillance systems.

What we have been considering at some length is the World of Private Information. It is only when we arrive at the final phase of the information processing system that the antecedent events take on meaning to the behavioral scientist. However, overt action in itself may tell us little about the intervening events that have taken place between Public and Private Worlds. The overt action must be examined within the context of a conceptual structure that employs an analytic rather than an intuitive approach. The technical structure we have presented seems to offer a guide and a means for analysis to real world problems.

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13. ABSTRACT

In this paper the roles and functions of man in the evolution and development of two complex specific systems within the Army operational environment are discussed. It is pointed out that throughout the course of historical development, the basic system functions and objectives have remained unchanged even though the system equipments have varied. With equipment changes, man's physical functions in system operation have also changed. In predicting the effectiveness of man in a future system operational environment, an approach independent of equipment differences is required. Such an approach in which man is conceived as an information processor is described. The approach is applied to the human operator roles in manned aerial reconnaissance and surveillance and in target acquisition.

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