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**On the Exploitation of Human Inductive Thought
and Intuition in Future Global Command
and Control Architectures**

by

Timothy J. White

June 1993

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On the Exploitation of Human Inductive Thought and Intuition
in Future Global Command and Control Architectures

by

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B.S., Mechanical Engineering, United States Naval Academy, 1987

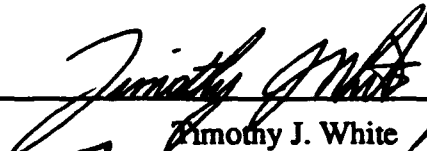
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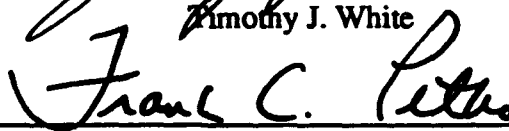
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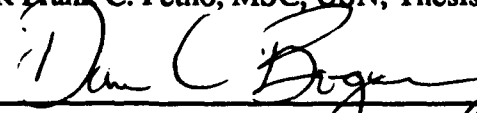
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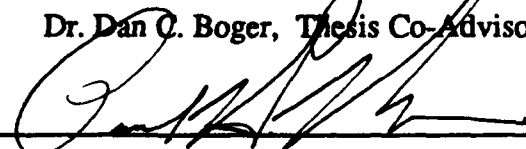
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ABSTRACT

Enabling technologies available today can be integrated to provide the necessary bandwidth, access, and computational power to support advanced global command and control architectures, but *humans* will ultimately use these architectures to select courses of action. People will continue to make decisions. The interface between the human operator and information collected, processed, fused, and disseminated by these advanced architectures is the element that injects greatest potential risk of failure within these systems. This thesis examines that interface.

The technical and doctrinal aspects of advanced command and control architectures are discussed. The concept of "information pull" is examined. The role information fusion plays in human situation assessment of the battlespace is delineated. Computer assisted inductive reasoning which exploits human intuitive powers is introduced as a potential design feature in the user interface. Recommendations for its inclusion in future command and control architectures are made.

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I. INTRODUCTION

*Perfection of means
and confusion of goals
seem, in my opinion,
to characterize our age.*

— ALBERT EINSTEIN

In the next decade, the United States' military will undergo a period of significant transition. As evidenced by recent world events, political policy will have a greater impact on military strategy (necessity to achieve UN mandate in support of coalition warfare), the new world order will usher in a new force structure (collapse of the Soviet Union), and technology will influence tactics (access to information and related processing/computing power). These changes will be accompanied by a shift in the infrastructure and methods by which the armed forces of the United States determine and implement optimal courses of action, allocate assets subject to environmental constraints, and direct forces against threats to complete a mission or fulfill an objective. These actions, in the collective sense, are called *command* and *control* (C²). The framework upon which effective C² is implemented is much more than simply making decisions and giving orders. This chapter serves to introduce C² and the concept of a supporting architecture of systems, procedure and personnel. Additionally, it provides a perspective on information and its value and limitations to the warrior. Finally, this chapter focuses the reader on the impact of technology and how the user or warrior will interact with information.

A. BACKGROUND

The method by which C² is exercised is steeped in tradition, defined by doctrine, and dependent upon technology. Arguably, tradition and doctrine are the foundation

upon which effective C² is accomplished. For, without the validity of tradition and the focus of doctrine, success on the battlefield would be fleeting. However, no less important is the framework that instantiates this process, namely technology. In the last 50 years, the art of command and control has added three additional dimensions — *communications, computers, and intelligence*. These new dimensions are directly attributable to the influence of technology in the conduct of modern warfare.

The new world order may dictate a smaller, highly trained military force. Political policy may mandate the consolidation of assets into Joint Task Forces (JTFs) oriented toward Contingency and Limited Objective Warfare (CALOW) missions, regional conflicts, and specific crisis-action scenarios. However, the impact of technology will be felt throughout the spectrum of weapons, missions, and forces. The structure upon which forces employ weapons in support of missions will continue to be built on the architecture of command, control, communications, computers, and intelligence (C⁴I).

B. COMMAND AND CONTROL = INFORMATION +/- CHAOS

Information may be considered as knowledge communicated concerning a particular fact or circumstance. Similarly, chaos may be considered as the state of utter confusion or disorder. In terms of the battlespace, the commander strives to obtain all relevant information concerning his¹ combat environment while chaos serves to disrupt, disable, and contradict these efforts. Undoubtedly, the world is more dynamic today than in the past. Relative to the military, but no less attributable to business, the scope of the term "situational awareness" continues to expand. Situational awareness is the human cognitive battle that represents the conflict between chaos and information. While Lord

¹Throughout this report, the masculine form of the personal pronoun has been used without exception. No specific gender requirement or bias is to be inferred from this; the more cumbersome combination forms such as "he/she" have been avoided for the sake of readability. The systematic alteration of gender was avoided as having even worse implication of bias than the use of a single form throughout.

Nelson had to worry about the wind, the battle line and little else, current commanders must concern themselves with the political and economic impacts of their decisions. Indeed, "Who did what to whom?" is compounded by "With what?" and "How many?", and a host of other questions.

Given that complexity, uncertainty, and adversity are all components of chaos, in this age of information and new geopolitical realities, chaos reigns supreme. The rate, complexity, uncertainty, and dimensionality of the commander's battlespace and the information he judges it by, are rapidly increasing. The military commander, in turn, must be flexible and have a high tolerance for ambiguity. He must be able to develop an information advantage in order to increase his enemy's level of chaos and defeat his enemy's command and control.

In an age where information is paramount, the initiative is underway to design a C⁴I architecture that enables a commander to command and control his forces more effectively. This C² is supported by communications systems that transmit the information processed and stored by computer systems that has been derived from intelligence systems.

Historically, command and control architectures have been predicated with a focus on the hardware within the system. New C⁴I architectures, represented by the Navy's Copernicus and the Joint Chiefs' of Staff "C4I For The Warrior," have evolved from an architecture driven exclusively by hardware to one focused on the operator and the operator's ability to achieve mission success. Today's C⁴I architectures are characterized by the concept of "producer push." Systems literally push volumes of indiscriminate, undifferentiated information onto users; information that is typically unusable because much of it is irrelevant and untimely. Commanders spend too much time sifting through, then discarding, messages instead of using the information they contain to develop and implement a war plan.

The new C⁴I architectures intend to shift from a "producer push" to an "information pull" mode of operation. Information pull refers to a concept which provides for on-site commanders to get the information they request. The architectures of these globally distributed C⁴I systems will be designed to provide automatically fused information to an on-site commander from a broad array of sensors. This information will be provided by a system characterized as seamless and supported by secure connectivity through multiple, highly flexible nodes to all operational elements and databases for any assigned mission.

C. HUMAN INTERFACE

Ultimately, command and control is a human decision making and problem solving process grounded in sound situational assessment. A person's decision is based upon deductive and inductive cognitive information processing. C² systems of the future, in order to meet the informational needs of the battlefield, will require computer assisted information processing technology. Additionally, the human decision making process will continue to be the dominant factor in the success or failure of command and control on the battlefield. Therefore, the user-technology interface will become a key issue in the development of future command and control systems.

This thesis will explore the "user interface" of future C⁴I architectures. These architectures have a specific design goal with respect to their human operators. They will be "user driven." They will be designed to empower the user to "pull" idiosyncratic information from a global network to enable that commander to develop an accurate, timely, and comprehensive awareness of any given tactical situation. This resource will be available anyplace, anytime, for any mission.

The important point about "information pull," and by extension, these new C⁴I architectures, is the focus on the "value" of information attributed to it by a user. The

ability to "get" information to the user unquestionably affects the success or failure of these new C⁴I architectures. However, the operator's cognitive ability to receive, process, analyze, and evaluate this information is the limiting factor upon which the outcome of future battles will be based. The C⁴I architecture must provide an operator with information. The operator, in turn, must be able to fuse that information to generate an accurate assessment of the tactical situation and then select an appropriate course of action. The role of the user-technology interface will be a key factor in the success of these advanced architecture initiatives.

D. SCOPE

Advanced C⁴I architectures will produce endless streams of information, but their ultimate performance potential is dependent upon the ability of people to use this information. Given that the linchpin of an operator's effectiveness is their cognitive ability, the effective use of these architectures depends upon the design of user-technology interfaces and the ability to fuse data into readily comprehensible information that supports sound, timely, and accurate situation assessments. Figure I-1 provides a synoptic view of the thesis and will be used throughout to provide the reader focus on the relevant issues.

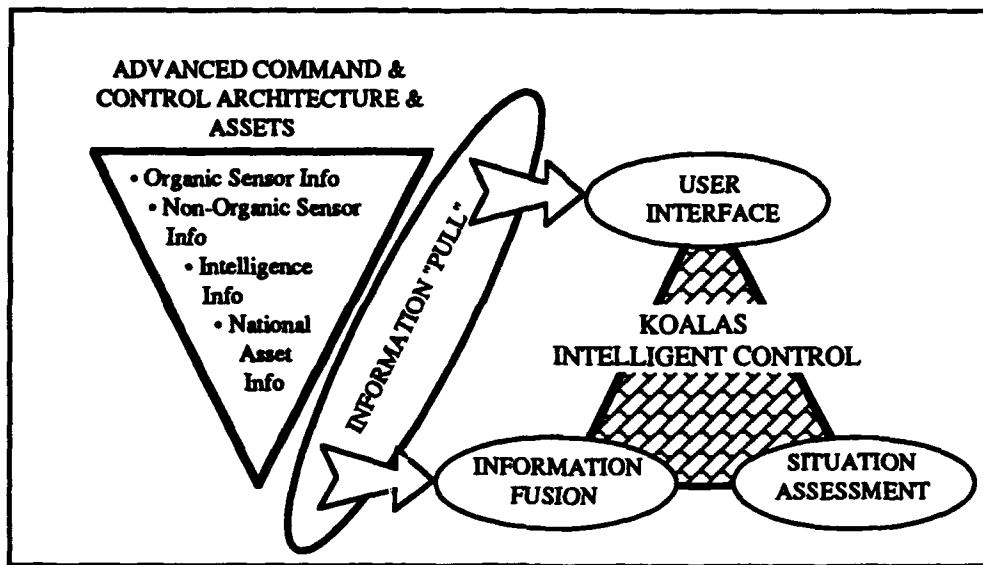


Figure I-1: Scope of the Thesis

This thesis will examine the concept of sensor or information fusion to determine how it can support rapid, accurate, and reliable situation assessment of the "battle space" by human operators performing various command functions in an information dense environment. As this volume of information rapidly increases, people will need to process orders of magnitude of information more than they currently do. The requirement for operators to assimilate huge amounts of data highlights the need for technology assisted pre—processing.

Computer assisted pre—processing is the subject of extensive research ranging from expert systems (ESs) to knowledge-based decision support systems (KBDSS) to artificial intelligence (AI). One thrust receiving limited attention focuses on developing a software interface that permits limited inductive processing by machines. Computer assisted inductive processing can aid the human operator in two ways. First, it helps the human operator fuse information. Second, it apprises the same operator of the tactical situation by assessing what the threat is and what the best response should be or even can

be given real world constraints. This notion of "intuition" is what sets a relatively new inductive system, the Knowledgeable Observation Analysis-Linked Advisory System (KOALAS), apart from other sensor fusion and situation assessment models.

As indicated by Figure I-1, this thesis will be organized in the following manner. Chapter II will provide an overview of the Copernicus and C4IFTW architectures. Chapter III will discuss the notion of "information pull" and current advanced information technologies. Chapter IV will address the concept of sensor or information fusion. Chapter V will analyze the idea of situation assessment with a view towards human cognitive limits. Chapter VI will discuss the specific initiatives for sensor fusion and situation assessment contained within the KOALAS framework. Chapter VII will explore potential future applications and recommendations to integrate KOALAS within the Copernicus/C4IFTW architectures. Finally, Chapter VIII will provide summary and conclusions. Because this thesis integrates several, nearly-disjoint areas of inquiry, a glossary of terms is provided as Appendix A. In most cases, only a quick definition or explanation is given with a more detailed discussion contained in the relevant chapter(s) of the text.

II. ADVANCED C4I ARCHITECTURE INITIATIVES

*No servitude is more hopeless
than that of unintelligent submission
to an idea formally correct, yet incomplete.
It has all the vicious misleading of a half-truth
unqualified by appreciation of modifying conditions.*
— ALFRED THAYER MAHAN

As indicated by Figure II-1, below, this chapter will discuss several broad issues concerning the advanced C⁴I architecture initiatives that are currently under consideration.

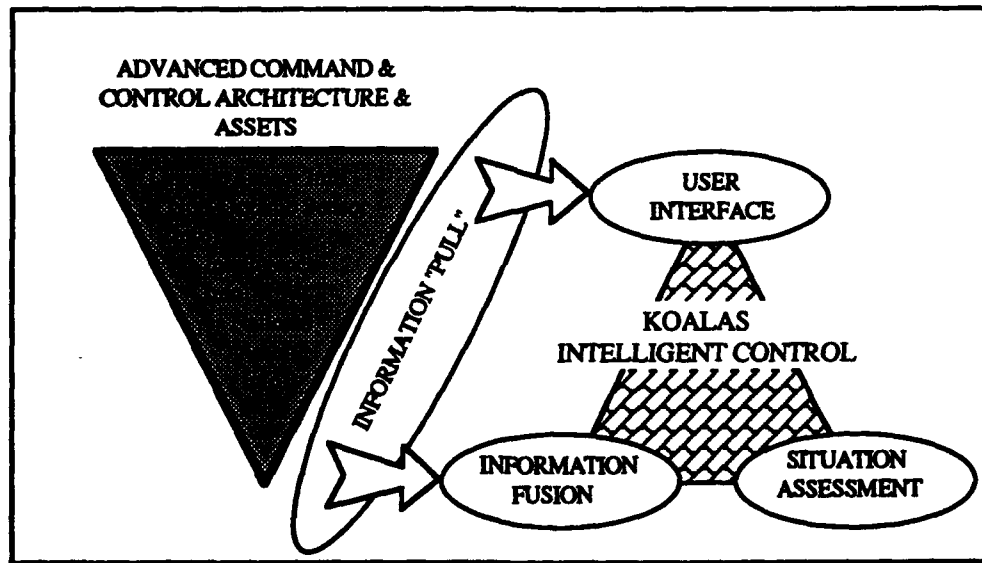


Figure II-1: Advanced C4I Architecture

The advanced architectures represented so simply in the above figure will achieve a level of interoperability, synchronization, data-transfer, and synergism heretofore unimaginable. For the purposes of this thesis, however, it is more important to view these initiatives not in terms of functionality, but as "enablers" to allow the human operator to "think" better. It is appropriate to present the environment, information needs, and the

goals that constitute these initiatives to better focus on the underlying theme of this thesis. While these architectures will provide access to virtually unlimited quantities of data and information, the real crux of the matter centers on providing the operator access to his virtually unlimited capacity to think intuitively.

A. THE NEED ... SOLVING TODAY'S PROBLEMS

It is important to understand the impetus for change, particularly when the enactment of that change represents huge expenditures of capital investment as well as a near complete overhaul in organizational infrastructure and procedures. Current C⁴I initiatives are a response to perceived limitations endemic to the defense organization and the systems it uses to command and control forces in an equally dynamic environment in which these forces will be employed.

1. Organizational and System Limitations

Typically, problems that occur or arise within an organization can be traced to two fundamental parameters: the way they do business and the tools they use. The Navy and the Department of Defense are no exceptions. While there many personnel, physical, and fiscal limitations are beyond the control of the Navy and DOD and serve to mitigate operational effectiveness, inefficiencies within the structure itself serve only to amplify these limitations, particularly within the framework of a C⁴I architecture.

In simple terms, C² is accomplished in today's environment by a collection and combination of sensors, computers, communication equipment and facilities, and procedures. The stovepipe nature of system¹ acquisition, development and employment is the major problem area. Loescher (1992) provides several generalized problem areas. First, there is a huge number of sensors in the current arsenal inventory. Second, each of

¹System is taken to mean sensors, computers, communication equipment and facilities, etc.

these multitude of sensors requires a different operating system and produces different report formats. Third, often times these sensors are governed by wholly different operating and control protocols. Fourth, these systems have an equally diverse number of organizational sponsors. Fifth, these systems are viewed in part and parcel, with little or no regard for the whole. Finally, each of these systems possess diverse, uncoordinated, uncohesive and conflicting operational goals. In short, we can not optimally operate within the battlespace because we are unable to manage and coordinate our own C⁴I systems — we've done it to ourselves.

Additionally, according to the Copernicus Project Team (1992), "four knots that bind the potential power of Naval C⁴I" exist and are discussed as follows. First, an inability to decant or separate operational from administrative traffic exists. Current systems provide no capability to achieve this aim other than "turning the radios off." The tradeoff here boils down to the lack of technology to manage the traffic flow, content, and make-up at any point in the C⁴I architecture versus the originating organizations lack of discipline to self-govern the output or service they produce. This becomes an important point relative to "user pull" and will be discussed further in Chapter III, Information Pull and Technology.

Second, once a "manual" separation of critical operational traffic has been achieved, it is often "in the wrong format ... and in the wrong form" The wrong *format* means many unique and independent formats from structured alphanumeric database to free-form analyst narrative. The wrong *form* means that the information is provided via hard copy rather than in a more easily manageable and manipulatable digital context. These two factors serve to complicate the data or information fusion process. The transliteration between forms and formats complicates the already difficult process of gleanng useful information from a multitude of sources.

Third, no cohesive or organized management and oversight of the C⁴I architecture exists. Essentially, there is no governing body which controls the use of the vast resources available to the tactical or JTF commander. In fact, one of the most difficult and time intensive chores a battle staff will undergo is determining what is available and who they have to ask to request support. The current C⁴I architecture is a hodgepodge of unitary sensors and complex systems controlled by competing agencies with uncoordinated and largely isolated agendas and goals which do not achieve the interdisciplinary cohesion necessary to meet the information requirements of future conflicts.

Finally, the military finds itself trying to function within a sphere of unfocused operational perspective. This condition may be likened to a Fortune 500TM corporation losing sight of the "bottom line" or "profit motive." This is attributable in large part to the changing dynamic of the world situation, social upheaval, economic hardship, or ineffectual government. Moreover, a common thread to these four problems and those generalized in the preceding paragraph is the technological underpinning which characterizes the development and use of the current C⁴I architecture. The case may be made that the United States military has lost sight of the *process* of command and control by being more concerned with the tools with which they conduct command and control.

2. The Changing Environment

Future military actions will be conducted in completely different regions, in varying degrees of scope and scale, and for different objectives. Indeed, the spectrum of conflict has not changed. In view of recent social, political, and economic upheavals around the world, the likelihood of global thermonuclear war and even theater-level nuclear conflict is substantially reduced. Military strategy is perceived to have shifted from containment to stability. Military action will no longer be between forces representing the

political, diplomatic, and economic aims of superpower nations. It has begun and will continue to be much more complicated than that.

The objective focus of military action is no longer on one nation geared for total domination, but on parity in conflict achieved through incremental and systematic confrontation. Conventional wisdom holds that conflict will not be between heavy mechanized infantry, armor, artillery and air forces on the plains of Central Europe. Nor will it be between opposing blue-water naval fleets on the high seas. Rather, it will be in localized regions where military action will be waged in unconventional fashion as a means of achieving economic parity, political freedom, and ideological liberty. Conflict will not occur in isolation. Conflict will happen on many fronts — in type, location, and environment — simultaneously.

Additionally, the enemy will become enemies; transitioning from a singular entity to plural entities. These enemies will be much more opaque; less clearly defined, more unclear, obscure, impenetrable and blurred. These enemies will exist to achieve objectives with which conventional ideology will be unfamiliar. These enemies will be less structured, but equally impassioned for their cause. In short, tomorrow's enemies are fraught with uncertainty and represent the unknown. Information - definition, collection, storage, transmission, manipulation, and presentation - reduces uncertainty and diminishes the unknown. Information will be the avenue of discovering the enemy. *Information* will become the commodity upon which battlespace is defined. *Information technology* will be the weapon with which the battle is fought. *Information management* will become a foundation of future command and control. Advantage in war and subsequent victory is achieved through the integration of weapons, technology, and man into a coherent and concentrated force. Situation assessment predicated on information fusion is the key to this integration.

Today's systems and architectures cannot accommodate the expanding demand or supply of information. Nor can it provide the requisite information handling capability. Nor does it enable the operator to make a decision, much less formulate alternative course of action. Nor does it perform adequately in the new warfare environments which will be encountered in the future. The war fighter does not suffer from a lack of information; but rather, he suffers from the lack of knowledge because he cannot assimilate and fuse the avalanche of information transmitted to him. *The current C⁴I architecture does not empower the operator to think.* This notion of "thinking" will be developed in Chapter III, Technology and User Pull, as well as in Chapter V, Situation Assessment. The time has come for change; not by evolution, but by revolution.

B. ADVANCED ARCHITECTURE OVERVIEW

The Navy's Copernicus and the JCS' C4IFTW architectures represent the military's response to the demands of change. These architectures will strive not to solve the problems briefly discussed above, but rather, eliminate them. These architectures will establish the military as the leader of information. Not in management, but in the command of information. Not in framework, but in horizon. Not in technology, but in the use of technology. Not in information collection and storage, but in information fusion and knowledge generation. Key items of the Copernicus and C4IFTW architectures are briefly introduced below.

1. Information Needs

Future warriors will possess even more capable, deadly, and sophisticated weapons systems and methods for using them. By extension, future enemies will possess similar capabilities. Consequently, achieving real-time cognizance and situation assessment of the battlespace and enemy capabilities will be the primary concern of the modern warrior. As outlined in the C4IFTW Objective Concept Coordination Draft, the warrior

has several broad area requirements to fight effectively in the future. These are known as "information needs." The following six items are drawn directly from the *C4IFTW Objective Concept Coordination Draft* and support the idea of KOALAS and interactive user-technology interfaces.

a. Risk Management

Risk is the volatility of potential outcomes. Risk management is the active participation in the make-up, design, and employment of assets (personnel, equipment, and systems) within an unanticipated and dynamic environment to achieve desired objectives. Risk management revolves around the spectrum of conflict within which future military operations will be involved. The focus here is on the *range of conflict* where the probability of military involvement is high and the consequences of failure are significant. Conflicts arising within this range of probable military involvement require a highly responsive C⁴I architecture. "...C⁴I must also be general-purpose, robust enough to control forces effectively, adaptable to different circumstances, and consistent with the threat environment." (*C4IFTW Objective Concept Coordination Draft*, 1992, p. 10) Nominally, risk management may center on "what if" scenarios and the selection of optimum courses of action.² Ultimately, those who best define and manage risk will find and maintain a strategic, operational, and tactical advantage over potential and active foes.

b. Adaptive Planning and Training

Planning and training for military operations will be a continuous and ongoing process. Future architectures must allow the commander and his staff to create and modify plans as the threat situation, tactical and strategic objectives, enemy, environment, and own forces status are continually monitored and automatically updated.

²These scenarios may well be generated within a model of the warrior's battlespace. This idea is expanded on in Chapter V, Situation Assessment, and Chapter VI, KOALAS Overview.

Being "adaptive" is particularly key in this context because of the necessity and desire to respond to user-defined input criteria and operational requirements. Thus the system will not only adapt to a dynamic and evolving situation, but equally important, to the changing perceptions of the war fighter.³

c. *Personalized C4I*

Individuals possess different cognitive abilities, leadership styles, and decision making methods. To be truly effective, C⁴I must respond and appeal to all warriors uniquely and individually. This concept is an extension of adaptive planning and training. Whereas the previous topic concerns the preparation for battle, personalized C⁴I focuses on the individual warrior in battle. The idea of "personalization" is the *prima facie* concept that defines the KOALAS user interface. As stated in the *C4IFTW Objective Concept Coordination Draft*,

Like an elaborate dog tag, each Warrior's style and favorite methods follow him into each new environment. As the Warrior learns, his personalized C4I learns with him. To achieve this, the C⁴I will be adaptive to each individual Warrior. It will interpret each Warrior's requests in light of past experience with that Warrior. It will translate between different styles of fighting and decision-making to weld the force into a synchronized machine. It will capture the intent of commanders and decisionmakers and disseminate this intent in the most relevant manner to all those who need to understand it. (*C4IFTW Objective Concept Coordination Draft*, 1992, p. 13)

d. *Battlespace Representation*

Again, this is an expansion from the concepts described above whereby each battlefield view is constructed to support the needs of each individual decisionmaker's role in battle. The commander "sees" what he feels is necessary to best make his battlespace decisions. This view will be built on available information from a variety and multitude of sensors and sources that is updated automatically from existing intelligent databases via virtual communication networks. The warrior and decisionmaker

³"Adaptability" to the warrior's perception of the battlespace is a key feature of KOALAS addressed in more detail in Chapter VI, KOALAS Overview, and Chapter VII, KOALAS Recommendations.

will interact with this representation or picture in terms of a situation assessment based on fused information. The C⁴I architecture "remembers" the past decision making and situation assessment profile of each warrior and applies that to future environments, enemies, objectives, and battlespaces. KOALAS would play a vital role in this picture construct by allowing the user an avenue of feedback and control of his battlespace representation in real-time. (*C4IFTW Objective Concept Coordination Draft*, 1992, p. 15)

e. Information Fusion

As envisioned, the C⁴I architecture will provide the warrior all information available so that he can prosecute his mission. Using his personalized C⁴I and battlespace representation features, the architecture will give the warrior knowledge of his battlespace in a manner that is the most meaningful. This knowledge will be generated from information from all possible sources — organic sensors, non-organic sensors, national level assets, synthesized intelligence summaries and analysis, to cite a few. The collection and fusion process will be transparent and controlled by the warrior. His picture will be continually updated by information that is automatically forwarded and integrated based on the warrior's demands. This idea of Information Fusion is further developed in Chapter IV, Fusion. (*C4IFTW Objective Concept Coordination Draft*, 1992, p. 16)

f. Environment Independence

The goal is to provide the warrior with the capability to fight in any situation or environment from the extreme heat of the Persian Gulf to the extreme cold of Antarctica for whatever the political or economic motivation. This will be achieved by designing the architecture and its supporting doctrine, forces, and equipment to operate in a modular format whereby they may simply "plug in" wherever and whenever required.

2. Goals

Similar to above, the *C4IFTW Objective Concept Coordination Draft* provides several C⁴I goals as a result of the identification of the warrior's information

needs. Satisfying the information needs of the warrior is the premise behind these advanced C⁴I architectures. Following is a brief summary of those goals relative to the necessity to accommodate human factors design criteria with regard to the KOALAS user-technology interface.

a. *Seamless Operations*

As noted in the *C4IFTW Objective Concept Coordination Draft*, seamless operations will be the "glue" that binds the multivaried and distributed elements of the architecture into an easily and readily usable system that supports the warrior. Objectively, the architecture provides the answers to the warrior's questions. Operationally, seamless means there are no disconnects or delays in providing these answers. Doctrinally, seamless means the architecture will be an integrated, cohesive, synchronous, and harmonious information infrastructure. Specifically, "... the Warrior's C4I interface must be simple, consistent, and transparent to the numerous diverse elements and networks that may come to play to service the Warrior's needs." (*C4IFTW Objective Concept Coordination Draft*, 1992, p. 27)

b. *100 Percent Interoperability*

This means the free exchange of information and dialogue and will be accomplished via "... standardized formats, definitions, data, applications, procedures, and human processes." Ideally, there will be no "price" or "penalty" in terms of incomplete or inaccessible information regardless of who the warrior is, his environment, or his equipment. Of particular concern, interoperability will support the common representation of the battlespace, information fusion, and situation assessment. (*C4IFTW Objective Concept Coordination Draft*, 1992, p. 28)

c. *Common Operating Environment*

This is an amplification and extension of the interoperability requirement. The goal here is to provide a familiar and common "look, touch, sound, and

feel" of the C⁴I environment. A common operating environment "... supports the warrior's needs for a common representation of the battlespace, an effective human/machine relationship, and operational 'independence' from the war fighting environment." Careful incorporation and design of "commonality" will enhance the user's cognitive abilities to perform sound and accurate situation assessment. (*C4IFTW Objective Concept Coordination Draft*, 1992, p. 29)

d. Over-the-Air Updating

The warrior will deploy with preplanned essential elements of information (P2E2I). Over-the-air-updating automatically provides the latest updates to this information based upon the warriors needs. This goal supports adaptive planning and information fusion. (*C4IFTW Objective Concept Coordination Draft*, 1992, p. 32)

e. Warrior Pull on Demand

This feature will be built on the concepts of personalized C⁴I, battlespace representation, information fusion, seamless and transparent operations, and contained within a common operating environment. *This is the single most important point from the perspective of the warrior.* In fact, information pull serves to completely shift the perspective away from ancillary and diverse organizations to the warrior. Information pull puts the warrior in a position to interact with his battlespace and control his environment with the most leverage. Information pull empowers the warrior by enabling him to make more informed decisions concerning his environment. Information pull subordinates the support functions. No longer will administrative requirements govern force structure, equipment allocation, or the configuration of operations. Servicing the needs and demands of the warrior will become the paramount objective of these advanced C⁴I architectures. Warrior or information pull will be developed in Chapter III, Information Pull and Technology. (*C4IFTW Objective Concept Coordination Draft*, 1992, p. 33)

f. Real-time Decision Aiding

While information pull represents the key objective concept of the advanced C⁴I architectures, the chief impact from the view of the warrior will be an increase in his ability to make effective decisions. Decision aiding involves the ability to manipulate and display appropriate information interactively with the user to facilitate sound and accurate situation assessment. This will be supported by the information fusion process. Fusion will provide the warrior with an information continuum — raw data, synthesized or processed intelligence, possible courses of action and associated risk alternatives, or a single answer. This decision aiding feature is focused on the warrior's cognitive abilities and will be the essence of the user-technology interface contained within these advanced architectures. Decision aiding will be further discussed in Chapter V, Situation Assessment, as well as in Chapters VI and VII dealing with the KOALAS concept. (*C4IFTW Objective Concept Coordination Draft*, 1992, p. 34)

3. Conceptual Summary

Thus, as envisioned by the C⁴I Architecture & Integration Division, J6I, and the Copernicus Project Team, these advanced command and control architectures will provide a distributed, user-driven information network or infrastructure. The users (own forces) will "plug into" this infrastructure anywhere and at anytime (environmental independence) to execute any mission. The infrastructure will be managed via multiple, flexible secure nodes. This information infrastructure will operate in a seamless and transparent fashion (information pull). Additionally, it will provide accurate and complete pictures of the battlespace and present the clearest view of the target set (information fusion and user graphical interface) based upon the demands of the individual warrior (personalized C⁴I). Finally, these architectures will empower the warrior to "think" better by providing advanced technology decision aids (situation assessment).

C. UNRESOLVED ISSUES

The central problem facing the United States' military today, and into the next century, will be to solve the nebulous integration/ interface structure between itself and the warriors it must support within the advanced C⁴I architecture proposals. It is incumbent upon the military to seize the initiative in defining the role, structure, organization, and capabilities within and in support of these new architectures. As discussed above, these architectures depend on the free flow of information at the demand of the user. It is the nature of this information that will enable the warrior to "carry the day" in his battlespace. *It is the nature of the user interface that will provide the requisite command and control decision aiding to ensure victory.* Following are several issues which need to be explicitly addressed within future C⁴I architectures.

1. Information Access

These advanced C⁴I architecture initiatives center around the warrior and his access to virtually unlimited, near-real-time, and fused — organic, non-organic, national level, and intelligence — information. This information will change the face of today's warfare. The lines between strategic and tactical military information will become blurred as the depth, breadth and volume of information supersedes the ability of doctrine to distinguish the difference. Simply stated, information horizons are expanding at unforeseen rates; the military community must meet this pace and have as its goal to exceed it.

2. Information Performance

The conceptualization of information within these advanced architectures is easier when approached from the perspective of "a means to an end." As envisioned, these architectures will provide the requisite technological capability, organizational infrastructure, and doctrinal procedures to support the armed forces completely. The

military must work within the information infrastructure to optimize its performance both from without and within.

a. Information Interface

From without, the military community must fully understand these advanced architectures and its simplicity of vision. This may be thought of as the "information-interface" and will be implemented through effective information pull and fusion practices. In terms of information, data is collected about the environment by various sensors, assets, and organizations and transported within the architecture on information exchange networks, the major communication pathways. This data will be transported to command centers in the operational theater or other warfare specific C⁴I nodes where it will be fused into information. From these distributed fusion nodes, this information is forwarded to the operational forces — a JTF, MAGTF, CVBG, or other — automatically upon demand. The operational commander can turn this information to tactical advantage for two primary reasons: 1) information connectivity to his chain of command via tactical command centers throughout the area of operations (AO), and 2) the on-line decision aiding features of his information interface which enable his increase in own force C² ability and decrease the enemy's C² ability.

b. Information Value

From within, the military community must understand the value and nature of information itself. This may be thought of as the "cognitive amplification or concentration" aspect of the user and will be achieved through sound situation assessment resulting from technological decision aiding. The process outlined in the preceding section will be transparent to the user. The warrior will not know where the information or derived battlespace representation comes from, but he may be assured that it is current, accurate, and precise. The technology is vital, but the key lies in the human element. Sound and

accurate situation assessment breeds confidence in the architecture, the system, the information, and oneself ... technology alone is a poor substitute for this confidence.

The human decision makers and their individual cognitive processes and biases are central to the confidence associated with accurate and effective situation assessment. Care must be taken to consider how the warrior will assimilate, perceive, and interpret the information which supports his situation assessment. Designing for this information *valuation process* is the essence of cognitive amplification.

D. OBSERVATIONS

Changes in the world precipitate changes in the operational environment in which military forces will be employed. In turn, this new environment stimulates change in the manner and method in which military forces will achieve their assigned objectives. The nature of information, its composition and structure, as well as its inherent value to the commander and war fighter, will be critical issues to be faced by the designers of advanced C⁴I architectures.

When considering the sheer volumetric explosion in available information, its modalities and media, it becomes critical to deliver the right information to the right individual(s) at the right time. Information and its derived C² value must be focused at the decision maker; it must provide a sound, relevant, and accurate unity of assessment; it must be flexible, responsive, and adaptable to the environment which it represents. In short, information must serve the warrior.

Finally, the full utility and value of information potential will only be achieved by designing for the human-in-the-loop. Understanding human cognitive strengths and compensating for human cognitive limitations and information processing biases will achieve greater operator effectiveness. The advanced C⁴I architectures presented in the

conceptual overview given above enable the warrior to perform to the best of his ability by empowering him to get what he wants, when he wants it, and how he wants it.

III. INFORMATION PULL AND TECHNOLOGY

*... 'the hardest part of communication
is the last four inches.'*

*That's the story in a nutshell:
how do we get information
from the machine into the head,
and how do we get information
from the head into the machine?*

- FREDERICK BROOKS

As indicated by Figure III-1, below, this chapter will discuss some of the broad issues concerning the notion of information pull and related technology, specifically as it relates to "user pull" and the "user interface." Appendix A contains a listing of critical terms.

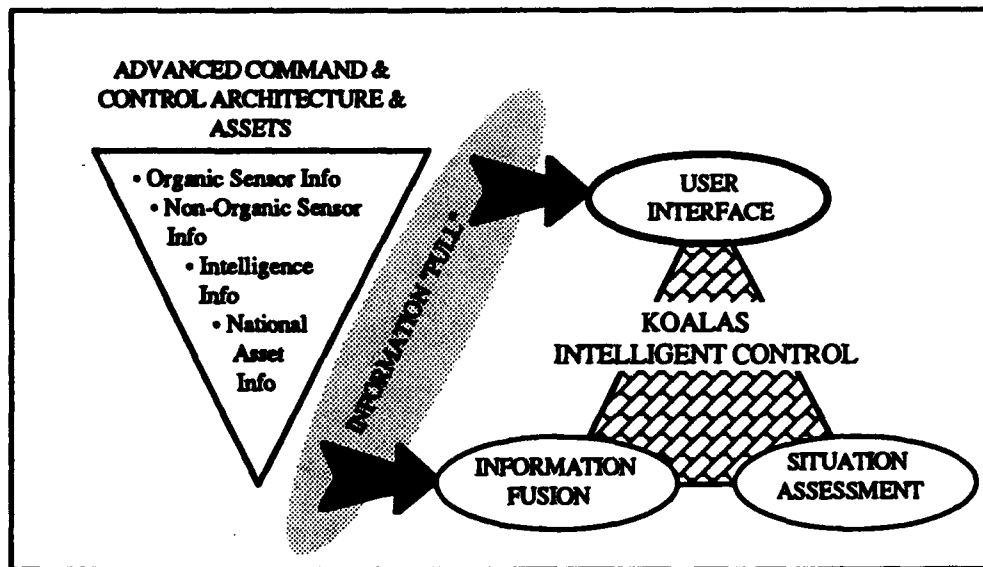


Figure III-1: Information Pull and the User Interface

One of the most critical and challenging objectives of the advanced C⁴I architectures is the necessity to enable the warrior to pull the information he needs to achieve his

assigned objective. As noted in previous discussion, this is a doctrinal shift from previous architectures that favored a "producer push" concept of operations whereby the operator was subjugated to the inconsistency and vagaries of agency produced information. Under the new architectures, the operator will define what is produced. This will be achievable through new and innovative technology applications, which will be managed by new warfare specialties. Ultimately, the essence of information pull will be found in the user-information interface.

A. INFORMATION PULL IDEOLOGY

Nominally, the information pull ideology is a simple construct — what the warrior wants, the warrior gets. Instead of requesting information from a multitude of agencies and governing protocols and receiving information from a multiplicity of sources in disparate formats, the warrior will simply ask for, and receive, information in near real time.

1. Characteristics

A few "key" operational characteristics that describe the concept of information pull are listed and briefly discussed below. They are by no means all inclusive, but are provided as a baseline.

a. *Transparent*

As mentioned previously, "transparent" simply means that the user or warrior is unaware of the processes involved in supporting his information needs. He has no *need* to know. The architecture and information pull provide the complete ease and comfort of "familiarity." The warrior makes a request for information and that information is presented to him in the form desired. The information infrastructure is responsible for interfacing his request within the architecture to provide the answer. This may be likened to the human phenomenon of "remembering." The "why's" and "wherefore's" behind the

human mind and memory are not completely understood, nor in this application should they be. Similarly, the notion of transparent information pull within these advanced architectures may be thought of as the information infrastructure equivalent to the mind's ability to remember.

b. Seamless

Similarly, seamless information pull also means that there are no "burps, hiccups, or disconnects" in providing information to the user. The architecture will be comprised of many organizations, systems, databases, sensors, equipment, and personnel. The warrior interface will take the information request and "agent" it throughout the network. The operator will be unconcerned with the politics of form or procedure; he will only be focused on function - making use of the information he demands.

c. Real-time

This will be a key feature considering the rapidity with which future battles will be fought. Providing the pulled information to the warrior in a timely fashion will be an overriding concern. Inconsistencies and delays in receipt of information will adversely impact the ability of the warrior to fuse his information thereby degrading his situation assessment and subsequent tactical effectiveness.

2. Infosphere

The term "infosphere" is analogous to the earth's atmosphere. In essence, everything that is the earth is contained within its atmosphere. Similarly, the infosphere will contain everything that is known about anything. Much like humans are constrained to live within earth's atmosphere, warriors will function within the infosphere. However, while there exist physical limits to earth's atmosphere, there will be no perceptual or cognitive limits to a warrior's infosphere. Additionally, while man remains subservient to the atmosphere, the infosphere will be controlled by the warrior.

3. Global Grid

The global grid is the communications backbone upon which the implementation of information pull will be achieved. It will be comprised of information highways with redundant surge capacity. It will feature high speed networking and contain personal communications systems, local, wide and metropolitan area networks. It will use advanced communications and computer technology and feature multi-level security. In short, the global grid will provide world-wide information connectivity.

4. Interface Function

This is the most important element or component within the dynamic of an advanced C⁴I architecture. In an age where "information is king," the user-information interface provided by new technologies will be the measure of success. It is not the application of technology that will solve the issues of seamless and transparent operations; nor is it the communications backbone or structure of the global grid; nor is it the "ether" of the infosphere. Rather, the role of the user-information interface will be the human mind — enhancing its ability to think and minimizing its cognitive limitations and biases. It will be at this interface where force is leveraged against an opponent. It is the nature of this interface that will ensure victory.

5. Limitations

It is equally important to understand current limitations that delay the development and implementation of the information pull ideology. While these limitations are diverse, they can be grouped into the three broad categories listed below.

a. Technological

Essentially, the technological "fixes" necessary to implement an information pull framework are available and resident within industry today. There is sufficient computer storage and processing capability to achieve many, but not all, of the requisite characteristics.

(1) **Over-the-Air-Updating.** The goal is to provide real time, automatic, and comprehensive updates to a war fighter's battlespace information. The limitation here stems principally from available communication bandwidth. New technologies are making ever greater inroads into maximizing the throughput over existing circuits. An essential feature on which the warrior will come to rely, is the fact that his information will be less time-late and of better quality than his opponents. Current technologies cannot guarantee this requirement.

(2) **Fusion.** *Fusion of a near continuous information stream represents the ultimate challenge of any tactical decision aid.* Information pull promises the continuous information. Current technologies are focusing on artificial intelligence and expert systems approaches to address the necessity to conduct timely, efficient, and accurate information fusion. These advanced technologies will be discussed below. The notion of fusion will be discussed in detail in Chapter IV, Fusion.

(3) **Information Availability and Gaps.** This is the kicker. Regardless of how well the information pull ideology works, undoubtedly gaps will exist in the available information. This will not be the fault of the architecture. Rather, this is a functional limitation of current sensor suites and systems, their capabilities, and simple paucity of resources. Technology can compensate for limited resources by providing new and innovative methods for sensing the battlespace. Current technology does not yet accomplish this.

b. Doctrinal

New doctrine that results from the collision of technology, new geopolitical realities, and a smaller force structure will be the glue that binds the advanced architecture and defines information pull. This doctrinal review is part of new, equally dynamic warfare area initiatives put forward by the component services, for example, the Navy's Space and Electronic Warfare, and will be discussed further below. It is important

to note that this doctrine is in its infancy and not widely accepted at present. One example of this embryonic policy is the notion of preplanned essential elements of information, or P2E2I. This concept was introduced in the last chapter on advanced architecture initiatives. The idea of being always prepared, always ready, and world-wide deployable is not new. The idea or doctrinal element of having pre-existing country or hot-spot essential elements of information is not new either. However, ensuring that before arriving in theater, what pre-planned information the warrior has is precisely what the warrior needs is extremely difficult to accomplish.

c. Human

Ultimately, the human limitations derive or boil down to the simple fact that people are not infallible — they are extremely prone to error, misjudgment, and incompetence. On the bright side, when it comes to implementing an information pull taxonomy, a well designed user-information interface will mitigate this problem. However, not all human failings can be compensated for or even anticipated. And then again, some failing may actually be blessings in disguise. A brief listing of some human limitations relating to information pull follows.

- *Precise information is hard to extract.* Generally speaking, information is generated at the behest or action of an individual. In terms of pull, it will be difficult to ensure that all warriors can function much less efficiently interact with the information infrastructure. It is difficult for people to clearly and easily frame queries in such a manner as to receive precisely what they "know" they want versus what they "said" they wanted.
- *The approach of each person to seeking information may be different, yet correct.* Continuing from above, not only is it difficult to frame a query, often there is more than one way to do it. This makes the design of an interface particularly intriguing and the training of warriors extremely rigorous.
- *It is hard to abstract good information acquisition when a person is under time pressure.* Many studies have shown that time pressures serve to reduce human performance in a given task. In a battlespace, the warrior will be expected, nay, will have to simultaneously seek information on multiple subjects in order to perform to maximum effectiveness.

- *Users have natural cognitive limits.* People often see only what they are prepared to see within a narrow attention span. It is particularly easy for warriors to focus on a particular action or skirmish thereby losing orientation and situational awareness of the battlespace. It may be that a ready source of information may exacerbate this phenomenon to the detriment of a warriors forces.

6. Summary

The issue of information pull is simple in nature; it is rather complex in execution. Two key factors which are foundations to the success of the information pull ideology are (1) the technology applications which may be used to engineer the information pull construct, and (2) the management of this construct. It is vitally important for all echelons, ranging from design to command, to understand what the warrior must do. This understanding will come from a simple question: what does the war fighter want to accomplish?

B. INFORMATION PULL "ENABLING" TECHNOLOGIES

As technology advances, particularly that related to information collection, processing, management and decision support, it will become apparent that the weak link of this architectural chain will not be in the communications pathways, organizational doctrine, or decision aids, but rather, will be found in the interaction of the warrior and the information, conveniently termed, the "user-information interface," which will be covered in Chapter V, Situation Assessment, and Chapters VI-VII, KOALAS. The mechanics or technology application of the user-information interface will be based upon concurrent and future research and development efforts. Some of these efforts are described in limited resolution below.

1. Intelligent Agents

According to the *C4IFTW Concept Definition Coordination Draft*, intelligent agents are "...software creations that incorporate artificial intelligence concepts." (*C4IFTW Concept Definition Coordination Draft*, 1992, p. 42) These "agents" will be "smart"

programs grounded in artificial intelligence technology that will help manage the infosphere and global grid (see above). Conceptually, they will maneuver through the information infrastructure to locate information relative to a user's request. These agents will support the warrior by providing current, accurate, and correct information even as the user's battlespace, environment, and needs change.

2. Databases

Databases become vitally important. The architecture must be able to store and manipulate the data. Additionally, this is where the warrior's requests for action will be acted upon. Thus, while the warrior's interface is not here, the databases represent the foundation upon which the effectiveness of his interface will be based. Essentially, there are four basic characteristics of these databases.

a. Preplanned

This feature is mandated by the plan to provide a continually updated and accurate list of P2E2Is. It is the very nature of being preplanned that ensures the continued readiness status of the United States military as world-wide deployable in short order.

b. Multimedia

Modern databases will have the capacity to store a wide variety of data and information in a wide variety of formats. It will be the ability to draw on text, tables, figures, maps, charts, graphics, imagery, video and the like which will best enable the warrior to not only get the information he needs, but view or interact with it in the manner in which he chooses.

c. Expandable, Reconfigurable

The databases will be designed from the ground up to be expandable in order to integrate as yet unplanned information modalities and media. Additionally, they will be dynamic in size allocation in order to best fit size and structure constraints within

environmental limitations. Similarly, these databases will have the ability to reconfigure the data internally from one form to another. This will ensure higher order functionality and a smoother warrior interface.

d. Intelligent

In a general sense, the databases will be "smart." They will have the ability to perform self-diagnostics to minimize, locate, and solve any potential problems. They will have the ability to communicate across the digital spectrum to verify content and resolve conflicts.

3. Synthetic Environment

A synthetic environment may be thought of as a simulation that is created using virtual reality technologies. The "players" in this environment will consist of geographically separate facilities linked together over a world-wide network. These physically separated and diverse "players" will share a common representation of the projected battlespace. A synthetic environment contains three components — live, constructive, and virtual. The live component is defined as operations with real equipment in the field. The constructive component is defined as war games, models, or other analytical tools. The virtual component is defined as systems and troops in simulators fighting on synthetic environments. (Starr, 1993)

4. Virtual Reality

Virtual reality is not so much a computer technology as it is an interface environment between the user and computer. Virtual reality was born out of an "... effort to find ways to couple human minds more tightly with computing machinery... [converging] with the older effort to create 3D illusions." (Rheingold, 1991, p. 60) Indeed, virtual reality will be a computer generated environment. The user will interact with this environment by interfacing with a computer via DataGloves™, "body suits," and head mounted displays (HMDs). Virtual reality or a virtual environment is a

"... representation of a computer model or database in the form of a system of virtual images which creates an interactive environment which can be experienced and/or manipulated by the user." (Furness, 1992) Virtual images are "Visual, auditory and tactile stimuli which are transmitted to the senses such that they appear to originate from within a three dimensional space surrounding the user." (Furness, 1992) The user-technology or user-information interaction is described in terms of a "virtual interface:"

A system of transducers, signal processors, computer hardware and software that create an interactive medium through which:

- 1) information is transmitted to the senses in the form of three dimensional virtual images;
- 2) psychomotor and physiological behavior of the user is monitored and used to manipulate the virtual images. (Furness, 1992)

The application of virtual reality technology implies a completely different view of how the warrior will pull information much less use and interact with this information. This technology will allow the computer to adapt to human limitations and functionality instead of training the warrior to operate under yet another constraint. Additionally, this technology promotes intuitive cognition and behavior. Allowing the warrior to see, touch, and manipulate his information environment as opposed to thinking about seeing, touching, and manipulating the iconic or symbolic representation of his battlespace will focus his attention and his effectiveness. As Bricken states, "Visceral access and intuitive interaction evoke our full sensory-cognitive capacity to comprehend." (Bricken, 1991, p. 366)

5. Natural Language Processing/Translation

This is the processing of natural language, for example, English or Arabic, by a computer to facilitate communications with the computer. In simple terms, this will enable the operator to enter into a useful and meaningful dialogue with a computer without having to know or program in specific higher order languages, like C++ or Ada. Additionally, natural language processing will allow for the ability to translate between

different languages or media. This will be particularly useful in a C⁴I architecture that not only supports forces from separate service components, often with their own vocabulary, but also in coalition warfare environments with forces from separate countries. (Gevarter, 1985, p. 233)

6. Speech Recognition

Part and parcel to natural language processing, speech recognition is the process that allows a user to communicate with a computer by speaking to it.

7. Visual Recognition

Visual recognition is simply technology that allows a computer to recognize and understand what it "sees" through a real-time optical input device or a stored digitized image. In terms of information pull, this technology would be of great value to a warrior as he is trying to make sense of his battlespace — for example, overhead imagery in an effort to conduct battle damage assessment. In conjunction with speech technology, this would allow a particularly useful and powerful dialogue between a warrior and a tactical decision.

8. Hypertext

Hypertext is an approach for handling text and graphic information by allowing users to jump from a given topic, as desired, to related ideas. In this fashion, processing information becomes more controlled by the user. It allows access to information in a nonlinear fashion by following a train of thought (intuition). It lets the reader control the level of details and the type of information displayed (battlespace presentation). Hypertext is a technology that facilitates the transfer of knowledge. (Turban, 1990, pp. 669-670)

9. Artificial Intelligence

This is the application of technology intended to produce "intelligent" computer systems. These artificially intelligent computers would be able to imitate human cognitive processes achieving far more accurate results. AI is essentially about the emulation of human cognitive behavior — the extraction of information and the generation of knowledge and understanding about the surrounding environment. (Daniels, 1987, pp. 3-12) AI will neither replace the warrior nor the human in general. However, considering the voluminous and overwhelming information available in a warrior's battlespace, some AI technologies would serve to make the warrior more deadly by allowing him to focus on his mission objective.

10. Expert Systems

An expert system is designed to capture the decision making and problem solving processes which are carried out by an "expert" well versed in both the theory, doctrine, and practice of the problem (battlespace) context. They can be thought of as computer programs that reach a level of performance comparable to that of a human expert *in a specialized domain*. An expert system is distinguishable from conventional application programs based on the following three characteristics: 1) it simulates human reasoning about a problem domain rather than simulating the domain itself, 2) it performs reasoning over representations of human knowledge via a knowledge base and an inference engine, and 3) it solves problems by heuristic methods. (Jackson, 1990, pp. 4) Additionally, an expert system differs from an artificial intelligence program in that: 1) it deals with subject matter of realistic complexity that normally requires a considerable amount of human expertise, 2) it must exhibit high performance in terms of speed and reliability, and 3) it must be capable of explaining and justifying solutions or recommendations should the user require it. (Jackson, 1990, pp. 4-5) Some specific, albeit not all inclusive, features of expert systems are discussed below.

a. *Connectionism*

Connectionism is an outgrowth of the notion of parallel processing. Connectionism represents massive parallel or simultaneous processing as opposed to the traditional approach of sequential processing. It is commonly held that this approach will be the key that ultimately unlocks the mysteries of human cognitive processing. Connectionism is an attempt to more closely mimic the manner in which the human mind operates. This is an approach focused on hardware configuration or construction where more conventional expert systems focus on software applications. The power of the human brain surely is not found in its processing speed (electro-chemical in nature), but rather in the nature of the processing itself. Whereas a CRAY[®] super computer may operate at 100 billion calculations per second, it performs these calculations in sequence, one after the other. The human brain, on the other hand, achieves orders of magnitude greater computing power by semantically encoding information and imposing organization on huge chunks of data. Obviously, if this type of tool can be effectively engineered, then the potential applications within a battlespace are great, for example, truly smart bombs. It is difficult to imagine the potential benefit and power associated with this technology in terms of information processing and command and control.

b. *Neural Networks*

These are algorithms used for detecting patterns in large amounts of data. Neural nets look at the relationship implicit in the data and develop a predictive model for use with further data. Neural nets appear to have very good predictive and classification abilities. However, neural nets do not provide criteria equivalent to statistical methods for evaluating the performance of the underlying model. In addition, the development of an effective, accurate, and valid neural net tends to be more of an art form. (Watkins, 1992, p. 134 and Sandman, 1992, p. 4) Neural networks mimic natural nerve-sets by linking together lots of identical elements, much like the human brain. These

elements, or nerve-sets, may be computer chips or contained in the software or cyberspace of a computer program. These neural networks can be taught to do things by changing the strengths of the connections between its nerve-sets. (*The Economist*, May 8th-14th, 1993, p. 92) The particularly attractive point of this technology lies in the ability to discern patterns in huge quantities of data. It is much more than a simple pattern recognition schema, however, because the associated predictive model may be useful in providing additional insight to a warrior about his battlespace.

c. Genetic Algorithms

These algorithms are enhancements to neural networks. Essentially, these algorithms exploit the evolutionary forces behind Darwin's theory of natural selection. The general idea behind genetic algorithms is to create a starting population of rules, find the better performing rules, and create new rules by recombining or mutating the components of the "parent" rules. They allow machine learning and natural selection to take place within neural networks which facilitates adaptability of the networks to adjust to new situations. While somewhat experimental, they appear to provide learning potential to neural networks and other algorithms. This feature would be of extreme value when considering the fact that the warriors battlespace is an extremely dynamic environment possessing virtually innumerable variables. In essence, the warrior's battlespace presents a continuous new situation. (Watkins, 1992, p. 134 and Sandman, 1992, pp. 4-5)

d. Fuzzy Logic

Essentially, fuzzy logic deals with situations where the question that is posed and the relevant knowledge possessed contain vague concepts. Fuzzy logic is an AI and expert system initiative that exploits the concept of approximate reasoning and is grounded in the mathematical theory of fuzzy sets. It is an attempt to simulate "normal" human reasoning. A conscious denizen of less precision and less logic

seems to be the anathema for computer programming. Indeed, uncertainty and approximation are being programmed in an effort to simulate or model the "gray" areas of decision making. These computer programs will eventually make more intelligent decisions by being able to understand the qualifying adverbs and adjectives associated with natural language processing. Fuzzy logic or fuzzy thinking may hold the advantages of providing the warrior flexibility, giving him options, freeing his imagination, be more forgiving, and allow for observation. (Turban, 1990, pp. 524-525)

e. Case-Based Reasoning

This is based on the notion that past experiences can often provide insights into future decisions or problem solving. A case is any set of features or attributes that are related in some manner and to which a comparison can be made of a current situation. The basis for comparison is similarity — to what extent is the current situation similar to or analogous to prior cases. Case-based reasoning can provide some adaptiveness to new situations and modify the case-histories based on new information. This feature would be valuable to the warrior in terms of "the lessons of history." The military develops huge databases of lessons learned from armed conflict and training exercises. Case-based reasoning may prove an excellent tool in tapping this resource. Besides, it sure would be nice to "know" what Napoleon, Patton or Nelson would do under similar circumstances. (Watkins, 1992, p. 134)

f. Inductive Expert System

This system is developed using an induction algorithm, discussed below, on a set of data obtained from past experiences. Induction algorithms attempt to acquire expert knowledge without the direct involvement of human users. This is for two primary reasons: 1) human experts are often scarce and expensive, and 2) experts often find it difficult to articulate their knowledge. This type of expert system may

be of immense value to a warrior because of the availability of "expert" tactical knowledge without the associated C2 overhead. (Dos Santos, 1992, p. 36)

g. Inductive Support System

An inductive support system is an interactive computer system designed to assist a decision maker based on classification rules derived from a training set of examples. An ISS incorporates decision aids intended to assist in the process of decision channeling. Decision channeling is the general property of an interface architecture that serves to support and shift the decision process. ISS have been recognized as a useful approach for converting data to information or knowledge. This system would be particularly useful in determining what additional or amplifying information the user or warrior should be considering asking for based on his current assessment of the battlespace. Additionally, an ISS may be useful in anticipating these information demands thereby reducing the cognitive load on the warrior. (Sandman, 1992, p. 7)

h. Induction Algorithm

This algorithm represents an attempt to develop a procedure by which the class of an object can be determined from the values of its attributes (inputs). The developed procedure is represented as a decision tree. Induction algorithms develop trees which continue to test inputs until the untested inputs provide no further information value. This notion is readily applicable to the warrior as he conducts situation assessment throughout his battlespace. This may be an aid in determining things such as "hostile intent" based on available, known and requested kinematic attributes or information inputs. (Dos Santos, 1992, p. 37)

It is valuable to understand the broad capabilities that these advanced technologies may provide. The most important feature that these technologies will promote is in the efficacy of the warrior himself. Warriors and leaders forget, they are inconsistent, and they allow emotional factors to control their decisions and actions. Warriors have difficulty in

dealing with and evaluating large amounts of data, complex information and different kinds and levels of knowledge. Technologies which enable the advanced C⁴I architectures will not prevent a faulty memory or emotional and inconsistent conclusions. Nor will they guarantee perfect situation assessment based on synthesizing data, information, and knowledge ... but they will ensure that right information is available to the right warrior at the right time to optimize the likelihood of making a right decision.

C. INFORMATION PULL WARFARE

The instantiation of these new, advanced architectures represent more than just a shift or transition in the mechanics of command and control. It is a clear, fundamental demarcation that stands at the turning point of two epochs in military art. Quality is fast becoming the watchword and replacement for quantity. The era of high technology war is upon us and will be fought on the sea and land, and in the air, space, and ether. As introduced in Chapter II, Advanced Architecture Initiatives, these architectures will act as "enablers" that function to transcend conventional limits of current C⁴I systems.

1. Electronic Fire

Of interest is the fact that the United States military is not the only organization bright enough to understand the implications of information and its impact on C². Fitzgerald (1993) presents several warfare trends based on recent and current Soviet-Russian military writings that are discussed in part below. First, the capability to conduct simultaneous combat operations throughout the entire breadth and depth of the zone of operations will be achieved. Second, as evidenced by operations during Desert Storm, simultaneous destruction of targets will be doctrinal. Third, target sets will be expanded to specifically include technology, scientific, financial, or other general military-economic engines. Fourth, an increase in combat actions of a combined-arms scope, where combined-arms is taken to mean sea, land, air, and space, or a notional JTF. Fifth,

military action will be based on a focused leveraging of force across all spheres of combat resulting in not only synergistic advantages but composite vulnerabilities to an enemy's counterforce. Finally, points one through five are completely dependent upon the architecture's ability to manage the explosion of information necessary to visualize and comprehend a dynamic and multivaried battlespace. What the Russian's term "electronic-fire" in reference to the above is translated as Space and Electronic Warfare (SEW) in current naval jargon. (Fitzgerald, 1993, p. 26)

2. Space and Electronic Warfare (SEW)

There have been many articles and books published recently which make use of a relatively new term — information war. The SEW commander will be the Navy's information manager or network administrator for its battle groups and be responsible for waging this "war." Similar conceptual developments are underway within all service components of the Department of Defense. Below is a brief summary of the relatively new naval warfare known as Space and Electronic Warfare.

a. Strategic Objective

As stated by Loescher, "The *strategic objective* of SEW is to separate the enemy from his forces, to render the leader remote from his people (to take command of his forces in effect), and control his use of the electromagnetic spectra." (Loescher, 1992, p. 1) The implications of this objective cut deep and have a broad swath. Historically, the decapitation of an enemy's leadership has never been a principal focal objective of any singular warfare area. Degradations in an enemy's C² have always been considered an ancillary or side benefit resulting from well orchestrated, force on force conflicts. This warfare area will leverage assets directly against an enemy's command and control architecture. The success of this strategic objective is contingent upon the capability to receive real-time, accurate, fused, and complete information about an enemy.

b. Target Set

Warfare areas must have identifiable and recognizable targets.

Loescher continues:

The *target set* consists of those systems, which when destroyed, yield the strategic objective. For SEW, the target set consists of the enemy leadership at its highest levels as well as at the battlefield level, its communications systems, surveillance and targeting systems, information processing, decision and display systems, electronic warfare systems, and weapons guidance systems. An attack on this target set is the epitome of power projection, the ultimate penetration of the enemy. (Loescher, 1992, pp. 2-3)

Without question this target set is clearly and directly focused at the enemy's command and control ability (information resources and infrastructure). The commodity that will be most sought after is information, both by and about the enemy. Information is the lifeblood of the enemy's communications and weapons directions systems; information is the heart of an enemy's surveillance and intelligence systems; information is the mind of the enemy's leadership and decisionmakers; information is the soul of the enemy's command and control. Control of information is control of the battlespace.

c. SEW Defined

Like all warfare areas, SEW is conducted in terms of warfare and support functions. Loescher continues:

...SEW is the destruction or neutralization of enemy targets and the enhancement of friendly force battle management through the integrated employment and exploitation of the electromagnetic spectra and the medium of space. It encompasses measures that are employed to:

- Coordinate, correlate, fuse, and employ active and passive systems to optimize individual and aggregate communication, surveillance, reconnaissance, data correlation, classification, targeting and electromagnetic attack capabilities;
- Deny, degrade, confuse, or deceive the enemy's capabilities to communicate, sense, reconnoiter, classify, target, and attack; and
- Direct and control the employment of friendly forces and the information necessary to provide for the administration and support of those forces. (Loescher, 1992, p. 2)

d. SEW Disciplines

The warfare support disciplines are operational security (OPSEC), surveillance, C⁴I, and signals management. The warfare disciplines are operational deception (OPDEC), counter-surveillance, counter-C⁴I, and electronic combat.

e. SEW Grid

SEW is composed of the surveillance grid, communications grid, and the SEW grid, much like the global grid introduced above.

f. SEW Commander

The SEW commander will be expected to manage the three grids described above. This overall concept will be the overarching doctrine governing the following spheres of influence.

- **Force Sensor Management** - this includes sensor management, collection management, and surveillance coordination. This will be a subordinate functional area to information management. The warrior in this role must possess an operational and technological understanding of all sensors that can impact the battlespace.
- **Electronic Combat** - this includes the maintenance and employment of force-wide electronic defensive capabilities and assets. The warrior assigned this role must have an operational and technological understanding of all electronic systems that can impact the battlespace.
- **Battle Space Management** - this includes track and target coordination throughout the battlespace. This functional area will be highly dependent upon the fusion process described in Chapter IV, Fusion. The warrior assigned this role must understand weaponry and surveillance assets, employment, tactics, and doctrine.
- **Information Management** - this includes managing the communication grid, the virtual networks that ride over it, and the overall advanced C⁴I architecture. The warrior assigned this role must understand communication. More importantly, he must understand the value of information, how and where it is derived, and its impact. Information will be the warrior's weapon. He must understand the potential of information gridlock as a result of own or enemy actions.

As Loescher states, "The issue is not whether SEW is needed; it is here. This issue is how best to conduct it, exploit it, and manage it." (Loescher, 1992, p. 4)

Information and its use is the key to the successful prosecution of the SEW mission. How the user interfaces with this information in terms of getting it, comprehending it, using it, and controlling it will be the operational "weak link." The implementation of information pull outlined in the first section of this chapter will be a milestone in the attainment of this objective. This will be achieved by employing the technologies described in the second section of this chapter. The establishment of the new warfare area, SEW, or as the Russians term it, "electronic fire," serves to validate the implementation of these advanced C⁴I architectures. Up to this point, the ideas of getting the information (pull), and controlling the information (SEW) have been addressed. Chapters IV and V discuss how the warrior will comprehend and use his information.

IV. FUSION

*We are in great haste to construct
a magnetic telegraph from Maine to Texas;
but Maine and Texas, it may be,
have nothing important to communicate.*
- HENRY DAVID THOREAU

As indicated by Figure IV-1, the focus of this chapter is on sensor or information fusion.

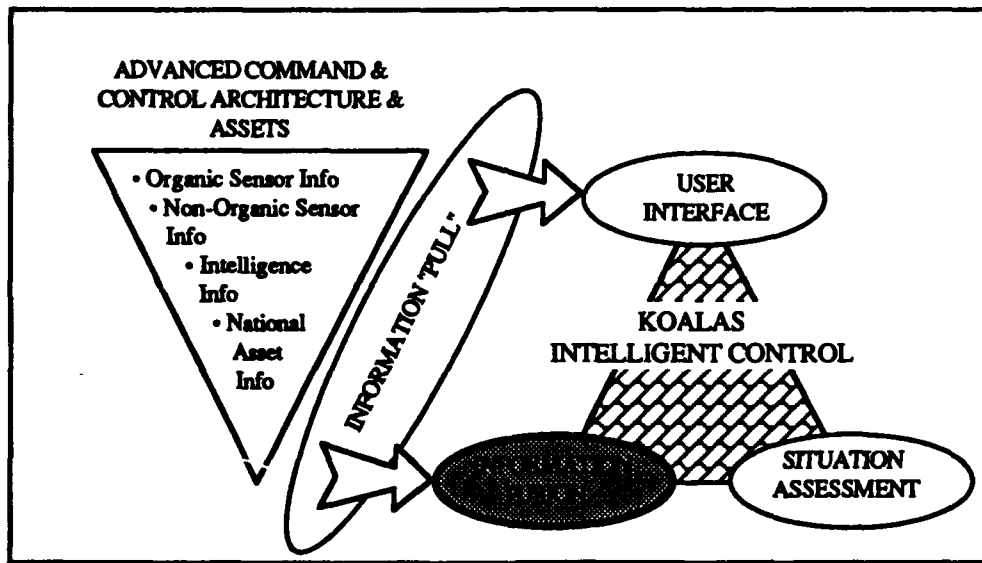


Figure IV-1: Location Within the Thesis

Next-generation tactical missions will rely on integrated, multi-sensor approaches for engagement information extraction. No longer can JTFs, let alone independent service components, rely on isolated, sparse, or incomplete information to wage war. Adequate information fusion is the key to the required positive and unambiguous situation and target assessment. In this context, information is treated as an output from a sensor as well as

data from other sources such as processed or "finished" intelligence. Future military operations will rely on the use of multiple sensors and information sources to increase the capabilities of intelligent machines, systems, and operators. The complexity, speed, and scope of modern warfare has increased. Consequently, the large numbers of diverse sensors in use today and the multiple sources of information concerning a mission objective has resulted in a peaked interest in the area of sensor and information fusion.

A. GENERAL FUSION METHODOLOGY

For purposes of simplification, the terms fusion, sensor fusion, multi-sensor fusion, data fusion, and information fusion are used synonymously. Fusion will be taken to mean the bringing together of information into a coherent picture. This will include information from not only organic sensors, but non-organic and national level sensors and assets as well. Additionally, this means information from other than simply electromagnetic, optical, and acoustic sources - for example, open source literature review and analysis as well as intelligence organizations.

1. Basic Areas of Sensor and Information Fusion

Even here, there is not a universal consensus concerning the fundamental elements that involve the fusion process. The fusion process involves four states: detection validation, correlation, collation, and inference. (Naylor, 1987, p. 95) The first module, detection validation, is used to control the integrity of the information within the database. This function may be performed by sensor pre-processing, existing database algorithms or human deliberation. Correlation is the process of searching a database for information that is similar to particular information of interest. Collation typically involves human judgment about the veracity of a report. Finally, the inference function is viewed as not being supported by software or hardware; the human is left to form hypotheses and draw conclusions. This is an elemental difference between conventional fusion algorithms and

systems and that proposed by KOALAS. This will be discussed in further detail in Chapters VI and VII .

However, according to Woolsey, the four fusion elements are: sense, classify and track, identify and analyze, and report. (Woolsey, 1987, p. 85) The sense element provides all raw source data. The classify and track element operates on the data sets to make the most of the raw information received from the sensors. The third element identifies and analyzes the information from the sets of sensors and combines the information to obtain an aggregate of the information. The final element here is to report fused information from the system.

Similarly, Comparato has devolved fusion into the following functions as well: associate, correlate, track, estimate, and classify. (Comparato, 1988, pp. 3-4) This particular functional decomposition is addressed later in this chapter. Ultimately, sensor or information fusion is grounded in the following four fundamental areas.¹

a. Sensor Operations

Operation of sensors deals with sensor or source control and tasking based on system feedback or operator inputs. This may be as simple as using one sensor to cue another sensor or based on an assessment of the situation, the operator directing a sensor to perform in a specified manner. Recent and continuing work in this field is researching the adaptive control and direction of multi-sensor systems in a high density target environment. Ideally, adaptive control would be sensitive to target densities and dynamics, sensor capabilities, and overall situation and mission objectives. (Blackman, 1988, p. 50) The issue of sensor operation is included in the KOALAS taxonomy under the guise of "intelligent control" and will be discussed in Chapters VI-VII.

¹The specific functional elements listed above are at various points part and parcel to the whole.

b. Track Formation

Track formation deals with detection and representation of kinematic information about objects of interest within the commander's battle space and environment. This information might be course, speed, altitude, and position to name a few. An example of this would be the genesis of an unknown air track in the early stages of the USS Vincennes-Iranian Airbus incident. Another would be the formation of an unknown air track in the USS Stark-Iraqi Mirage/Exocet incident during Operation Earnest Will in the Arabian Gulf.

c. Quantity Estimation

Quantity estimation deals with the grouping or configuration of specific contacts or tracks in the context of the surrounding environment - for example, a pair of aircraft (the "lead" and his wingman) or a "raid" of nineteen attack aircraft. Following the preceding example, in both instances these aircraft were determined to be operating alone so the quantity estimation was ruled as a single aircraft.

d. Higher Order Inferences

Making higher order inferences deals with attempting to discern target identity, intent, or enemy order of battle by forming hypotheses and drawing conclusions from available information. Current initiatives are investigating the use of Artificial Intelligence (AI) applications to assist human operators in this endeavor. This notion was introduced in Chapter III, Information Pull and Technology. Following the existing examples, in the case of the Iranian Airbus, that track was incorrectly inferred to not only be an Iranian F-14 tactical aircraft, but to be on an attack profile (an inference drawn from the kinematic and quantity data of single aircraft, inbound vector heading, descending altitude and the fact that the aircraft did not respond to verbal warnings issued over established communication guard circuits). In the case of the Iraqi Mirage, that aircraft was correctly inferred to be of Iraqi nationality (based on flight profile and electronic emissions)

but was incorrectly inferred to be non-hostile, or at least non-threatening. Interestingly, this was primarily a result of preconceived notions (bias) on the watch teams; attention was focused on the Iranians at the time. The Iraqi's had very willingly cooperated with established de-confliction procedures. The results of inference error can be disastrous.

2. Fusion - An Imperative

Given that what Clausewitz termed the "fog of war" is always present regardless of how well prepared, trained, equipped or notified a military force is, what value can there be in investing resources and time to develop what may be potentially barely adequate information schema? This is a difficult question to answer in detail. However, according to Clausewitz again, it is a simple problem to frame: reduce the inherent "friction" that contribute to this fog. Clausewitz believed that a reduction of friction occurred only through the actual experience of combat, armed conflict, or war. However, prudent military forces will take advantage of any and all technologies that will gain them even the slightest advantage in war. Thus, while the vagaries, ineptitude, and incompetence of individuals will always remain, sensor fusion technologies in support of situational awareness may minimize these detractors.

Suffice it to say that information fusion is difficult for a variety of reasons. Lakin and Miles have presented an eloquent discussion on some problems associated with information gleaned from within and without the battlespace. They list 14 reasons to substantiate the need for fusion which are briefly summarized below. (Lakin and Miles, 1985, pp. 234-235).

a. Incomplete Information

For a particular object in the battle space, each information source provides data on a subset of that object's properties. There is no single sensor which gives all the details to the accuracy (in the age of precision guided weapons, ground truth) and timeliness (given the rapidity with which the tactical scenario changes, real time or as near

real time as can be had) required. Therefore, it becomes important to combine information from a number of different sources.

b. Uncertain Information

It is certain that information from different sources refers to the same object, then it becomes simple to combine this information. However, this certainty does not exist and it is certainly impossible to remove all uncertainty from the battle space.² Hence, the need arises to correlate information from different sources to reduce uncertainty.

Unquestionably, in a perfect world there would exist perfect sensors, perfect information sources, and perfect information. In the real world, however, this is simply not the case. Thus, many problems associated with developing adequate sensor fusion technologies and methodologies arise from the nature in which uncertainty is handled.

(1) **Source Configuration.** Systems and sensors are generally designed to operate in a perfect environment that has been gracefully degraded by the system designer or engineer. Often, the vagaries of nature or human design are inadequately compensated for in this interaction. One has only to look at the self-propagating electromagnetic interference (EMI) environment that Navy ships operate in to visualize the potential for induced uncertainty that exists within these organic information sources.

(2) **Information Handling.** Many of the mathematical and statistical algorithms associated with data handling are specified to only a certain degree of accuracy. Additionally, there is a need to mathematically transform information from one sensor so that it approximates or mirrors the form of another. Typically, this involves

²Again, this represents Clausewitz' notion of "friction" and "fog" in war.

assumptions of statistical independence or simplifying assumptions concerning the nature of the uncertainties, for example, uncertainty caused by white noise.

c. *Ambiguous Information*

The kinematic properties of an object often represent the focal decision criteria about how to respond to perceived threats (witness the perception of an inbound and *descending* air contact in the USS Vincennes and Iranian Airbus incident). However, some sensors may provide poor positional information but good identity information, thus giving rise to considerable ambiguity. Data which stimulates perceptions of the battlespace is indeterminate, misleading, and potentially deceptive — the justification to combine information from a variety of sources is clearly evident.

d. *Error*

People make errors — in judgment, calculation, and execution. Machines, sensors, organizations, and procedures that handle information are constructs of the human mind, hence these constructs to detect, collect, and process information contain sources of error. Thus, while the nature of these systems contain sources of error, one way to reduce that error is to view information from the breadth and depth of a focused or fused perspective.

e. *Battlespace Complexity*

The battlespace confronting the warriors of today and tomorrow is expanding dimensionally and contextually at ever increasing rates. The warrior is no longer anchored in warfare areas that are linked to static dimensions. Objects within the battlespace are more intelligent, more accurate, move faster and possess greater lethality. The comfortable bipolarity of world affairs are days of a bygone era, replaced with uneasy tensions about enemies that are as yet unrecognized, unreconnoitered, and wholly unfamiliar. In sum, the volume of the battlespace is increasing, the dimensions of the battlespace are dynamic, the weapons of the battlespace are deadlier, and the participants in

the battlespace are unknown. Technology and computers provide the capacity to collect, process, and disseminate the information that will be necessary to fight the war. The human-technology interface will be the engine of this complex environment. Man will provide the motive force that will engineer victory.

f. Spectral Diversity

Information is derived from a wide range of disparate sources; for example, organic (radar, electronic support measures (ESM), acoustic), non-organic (datalinks, etc.), national (electronic and human intelligence), and so forth. Each of these sources possesses some or all of the organizational procedures, operational guidelines, equipment inaccuracies and failures, and personnel cognitive limits and biases that contribute to a wide ranging and varied list of possible information degradations. The great paradox is that it is in this very multitude of information sources that lies not only the problem of fusion, but the essence of the solution — borrowing from a tenant of Gestalt psychology, the whole is greater than the sum of the parts.

g. Geographic Diversity

The sources of the information are geographically separate, contributing to resolution and precision inaccuracies. It becomes problematic to resolve manners and modes of measurements to a “correct” ground truth.

h. Human Factors

People are limited in their cognitive ability. People exhibit error and biases in judgment and decision making tasks. These limitations occur at all levels of interaction with other people and/or machines. These limitations, then, would carry over into the realm of managing a multitude of independent sensors or other sources of information about the battlespace. Information fusion is one solution which minimizes these particular impacts since human cognitive limitations would not be applied to separate and distinct information which compound error.

i. Temporal Diversity

Regarding the short time intervals placed on the value of information in a tactical situation, it is critical that information be correctly "time-tagged" for further correlation, virtually impossible with current separate, convoluted systems.

j. Error - System Error

System error arises from design faults, system failure or inappropriate application. In addition, system error may arise from the system simply being uncalibrated or inaccurately calibrated. Errors may arise from the attempted integration of incompatible systems. These are but a few. Information fusion may minimize the degradations felt by system errors.

k. Communication

The issue here stems from the necessity to communicate between sources, sensors, controlling agencies, supervising authority, and the warrior. A limited bandwidth exists in which to execute effective command and control. The tradeoff seems to be between the communications capacity that ensures command with the control of sensors, sources and forces. Information fusion may "free up" precious bandwidth, guaranteeing effective command and control, without lessening the access to this information.

l. Sensor Control, or Survivability

An often overlooked aspect of information fusion is the survivability of the information sources themselves. It is desirable that sensor systems have the ability to operate somewhat autonomously; that is, without constant and ubiquitous oversight by a human supervisor or maintainer. However, this implies that a sensor will be able to determine from available information in a decidedly unstable information environment, how to best operate and manage itself from as a minimum, locally available information. In an information and C⁴I architecture envisioned within the Copernicus/C4IFTW initiatives, this

will be easily achievable since local information is global information and global information becomes local information.

m. Track (information) Maintenance

This may be viewed as synonymous with information quality. The question here is a determination of whether or not information should be maintained at all tactical commands and above or should tactical commands maintain only the information requisite for fulfillment of their mission. This issue is particularly pertinent within the scope of a JTF where the transition from one tactical force to another is particularly opaque. Problems arise in the allocation of assets to meet multiple demands in a constrained environment. Given that adequate physical asset distribution can be accomplished, the fusion aspect then becomes focused on the reconciliation or cohesion of separate information databases into a composite and accurate picture for the battlespace warrior. This is simply a microcosm of the broader issue of information fusion recumbent as an integral piece of the tactical force. In other words, at this level, information fusion is not part of the architecture, it is the architecture.

n. Sensor Allocation

When dealing with a multitude of varied sources of information, the issue of allocation of resources becomes critical. The commander must give attention to managing, operating, maintaining and evaluating the performance of his many assets on a case by case basis. A sensor or information fusion schema would reduce this management effort as well as make information gaps³ transparent to the commander since the fusion schema would support redundancy and overlapping sources.

³Recall discussion in Chapter III; regardless of how of how well the information pull ideology works, gaps will exist in the available information. This is a functional limitation of current systems and a paucity of resources.

Generally speaking, the information regarding a particular battle space environment can be expected to be incomplete, inaccurate, ambiguous, conflicting and subject to deliberate deception and interference from the enemy. Thus, as discussed above, sensor and information fusion represent a solution to aid the commander to obtain the maximum amount of value from the available information concerning his battlespace.

B. INFORMATION FUSION

For pedagogical purposes, the notion of fusion is more easily understandable in the context of a system. Thus, the development of the basics of the fusion process will be illustrated with several diagrams and ensuing explanations. In the overarching sense, fusion may be thought of as a process with outputs derived as a function of the inputs. Figure IV-2 is representative of this notion. (from Byrne, et al., 1987, p. 105) Here, it is easy to visualize a function termed data- or information-fusion. As indicated, the inputs may be, but are not limited to radar, IFF⁴, ESM⁵, intelligence, acoustic or data link information. Additionally, this information has relevance derived from other inputs such as the environment, plans or policy, or other discriminating events.

Ultimately, this information is fused and viewed by the decision maker or commander as an output of this process. The additional outputs labeled within parentheses indicate ancillary factors which may be of importance to a commander. Specifically, "interpretation" represents an AI or ES output that may provide some insight into the information of a synergistic nature. This will be amplified, later in this chapter, but more explicitly in Chapters VI and VII relative to KOALAS and its ability to provide interpretive feedback to the operator or commander regarding the value of information and an

⁴Identification Friend or Foe

⁵Electronic Support Measures

interpretation of the tactical situation (situation assessment). Additionally, as mentioned in Chapter III, Technology and User Pull, often times a key attribute which defines the user acceptance of a decision aid, whether an ES, KBDSS, or other AI application, is the ability of the decision aid to provide its decision logic or "explanation" of how and why it arrived

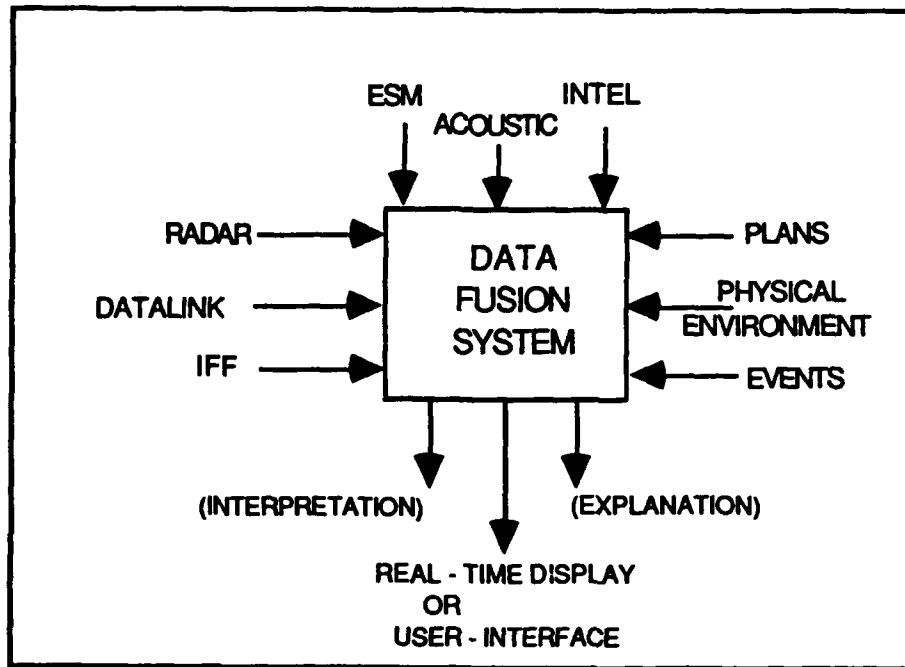


Figure IV-2: Simplified Fusion Schema (after Byrne, *et al.*, 1987)

at its conclusions. Again, this notion will be addressed in Chapters VI and VII. It is important to note that this process is not viewed as being controllable or necessarily influenced by the commander directly. This point will become of primary concern in later chapters as the discussion surrounding the human-technology interface is developed. All in all, fusion appears to be a rather simple function to describe, but it is usually not as easy to perform, model, or analyze.

A representative fusion system and pertinent functionality is displayed in Figure IV-3 (Comparato, 1988, p. 3). The system contains a variety of radio frequency (RF), infrared (IR), and electro-optical (EO) sensors for threat warning (TW), search and track (ST), and fire control. It is important to note that these are but a small sample of sensors and information sources available to a commander. Additionally, while a sensor may be configured to perform a certain function such as search or fire control, it is the compilation or fusion of their respective information contributions that contribute to situation assessment and human cognitive performance. Not indicated in this diagram but easily configurable would be the addition of sensor pre-processors. This would allow many functions associated with sensor operation to be accomplished at the sensor level.

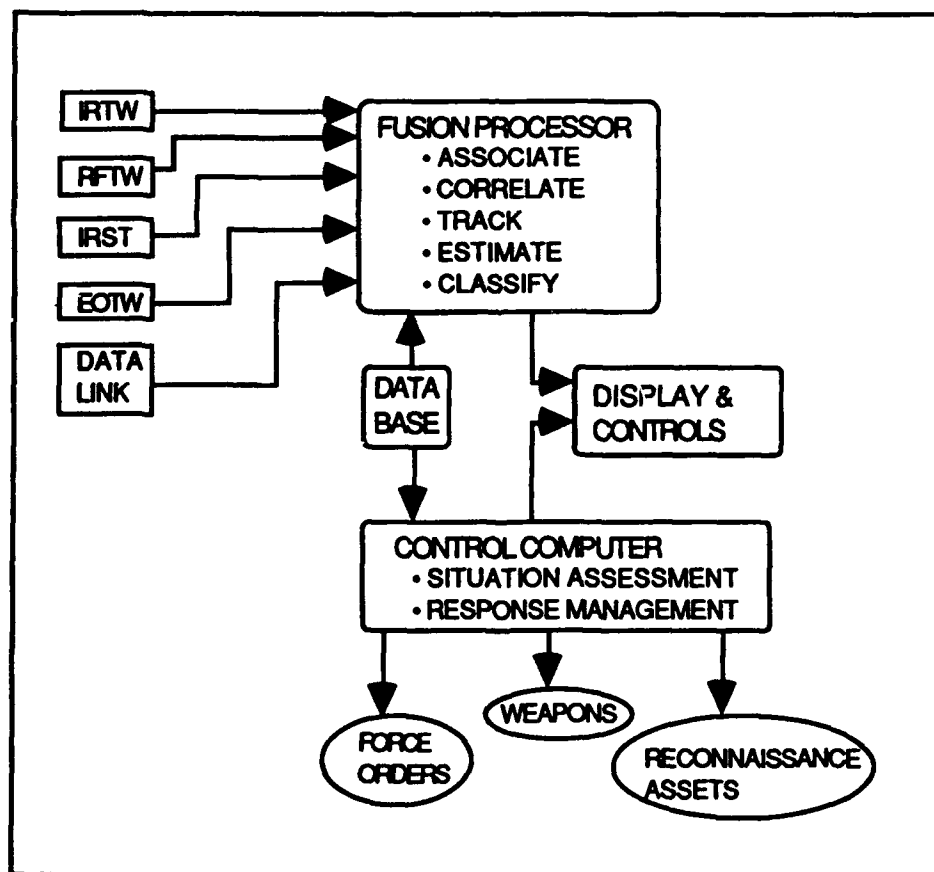


Figure IV-3: Multi-sensor System Functions (after Comparato, 1988)

This would have advantages such as minimum time-latency and easier configuration for fault tolerance. The fusion processor combines the raw information from different sensors to enhance the target classification and state estimation. While this figure is representative of a sensor suite whose utility is limited to a small part of a battle space environment, at the functional level it is completely representative. The fusion functions result in highly accurate and confident identification in order to properly select responses to the assessed situation and allocate resources such as sensors and countermeasures. Not indicated in this figure, but to be discussed later in Chapter V, Situation Assessment, will be the notion of "intent" and one initiative that presupposes to help solve the determination of this factor. Measurement data is provided by each sensor independently. Tracking is performed autonomously when gains in target state estimation or threat identification can be realized.

Comparato (1988) envisions a system where the fusion function operates in one of two modes depending on the threat environment: surveillance or threat warning.⁶ In the surveillance mode, the system is in a low stress situation, probably in passive operation. The fusion function is receiving data from all onboard (organic) and off-board (non-organic) sensors and is performing the functions of coordinate alignment, time propagation, association, correlation, and track update. Classification of the threat information is attempted on a sensor basis where possible, and is refined in fusion using all of the available sensor data. Some sensors can provide good classification autonomously while other sensors provide accurate angle or range data but no classification. The fusion of the data will combine the attributes of each sensor in one master file. The updated master track file is then transmitted to the situation assessment function, the integrated display subsystem and the fire control subsystem. In the threat warning mode, the system

⁶Under the KOALAS concept this is more than just a "binary switch." KOALAS may permit a finer gradation of environment or threat determinations which can further optimize sensor performance and situation assessment. This will be discussed in Chapter VI, KOALAS.

is under stress due to the identification of an impending threat. As envisioned by Comparato (1988), the two modes are non-exclusive. The surveillance mode operates continuously and the threat warning operates on a demand basis.

Figure IV-4, again, adapted from Comparato (1988), details the decomposition of fusion into subfunctions. This model assumes each sensor works autonomously and asynchronously in time and space. Additionally, absent in either Figure IV-3 or IV-4, corresponding to each sensor would be detection and track level preprocessors. Hence,

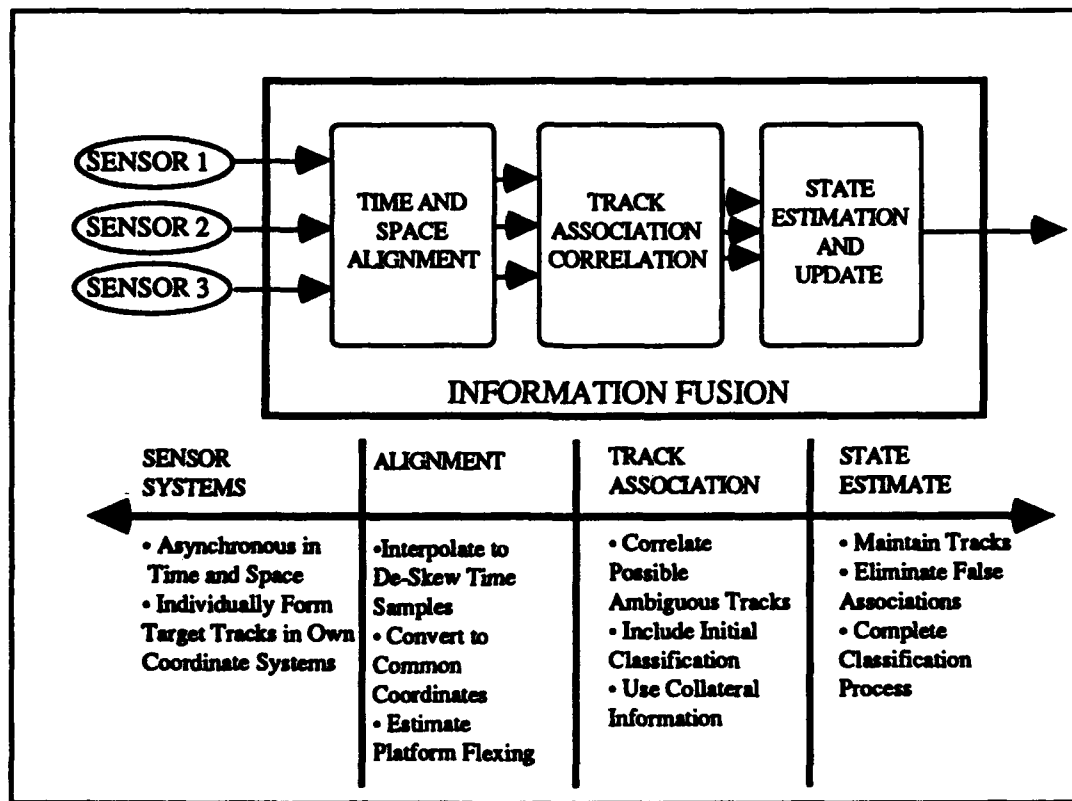


Figure IV-4: Specific Fusion Functions (after Comparato, 1988)

individually formed target tracks are provided by each sensor to the fusion function in each sensor's own coordinate system. The fusion processor then performs the following six subfunctions:

- *time propagation* - track files which have state vectors will be "time propagated" to the fusion update time.
- *coordinate alignment* - the sensor data need to be referenced to a common origin and compensation provided to sensor misalignment.
- *association* - the tracks, reports, and information from different sensors/sources need to be compared to determine candidates for "fusion;" attribute tests, kinematic tests, and probabilistic tests are utilized. KOALAS may provide an additional "intuition" test.
- *correlation* - the results of the association are then processed to determine the track pairs which will be fused.
- *track update* - the tracks which "best correlate" are used to update the corresponding state vector; the output is an updated composite track file.
- *classification* - the tracks are examined and an assessment is made in an attempt to determine the target type, lethality, and threat priority.

The fusion function extends from the measurement data to the master track file and until threat warning indications have been developed. For each sensor, signal processing is necessary.

The next step is track processing, which is adapted to each sensor in order to produce either track file or a time history of reports. Time propagation and coordinate alignment create data with common reference points in time and space which is necessary to blend data. This blending or fusion of the data is performed to create one master track file with all the positive attributes of each sensor. This master track file is then available to situation assessment, a concept further discussed in Chapter V, Situation Assessment. Fusion also performs sensor control, monitoring, and cueing.

Academically, fusion is a fairly simple problem space within which to operate. However, within the scope of this problem, some work has been performed in the context of sensor integration. While this may appear to be a rather finely discriminating use of terms, Luo and Kay have presented an elegant case, explanation, and discussion. Figure IV-5 is adapted from Luo and Kay as is the following explanation. (Luo and Kay, 1988, pp. 42-44)

In the context of Figure IV-5, multisensor integration is represented by the whole of the diagram whereas the fusion element refers to the circular nodes in the center portion. Integration is the systematic use of the information provided by multiple sensors or sources to assist in the accomplishment of a task by a system. Fusion is thought of in a more restrictive sense as any stage in the integration process where there is an actual combination (or fusion) of different source or sensor information into one representational format. A key point established by Luo and Kay (1988) is that the distinction between integration and fusion separates the more general issues involved in integration of multiple sensory devices at the system architecture and control level from the more specific issues involving the actual fusion of sensory information. For example, in many integrated multisensor systems the information from one sensor may be used to guide the operation of other sensors in the system without ever actually fusing the sensors' information. More accurately, the scope of this thesis is on the level of sensor or information integration as represented by Luo and Kay (1988) and not their more restrictive notion of fusion. For the purposes of this endeavor, fusion and integration will be viewed as complementary, if not synonymous terms, and "fusion" will be used hereafter.

Thus, while Figure IV-5 represents a general pattern of fusion in the context of this thesis, the actual information from the sensors or other sources is fused or combined at the nodes in the figure. In the figure, n sensors are interlaced in a fusion methodology to provide information to the system—in the terms of this paper, a command and control system within the Copernicus or C4I/TW architecture initiatives. The outputs (raw information) x_1 and x_2 from the first two information sources are fused at the lower left-hand node into a new information representation schema, $x_{1,2}$. In a similar manner, the output from all n information sources could be fused in the fashion indicated. The dashed lines from the system to each node serve to illustrate the possibility of using some type of

interactive information from the system (for example, feedback from a world model or KOALAS) as part of the fusion process.

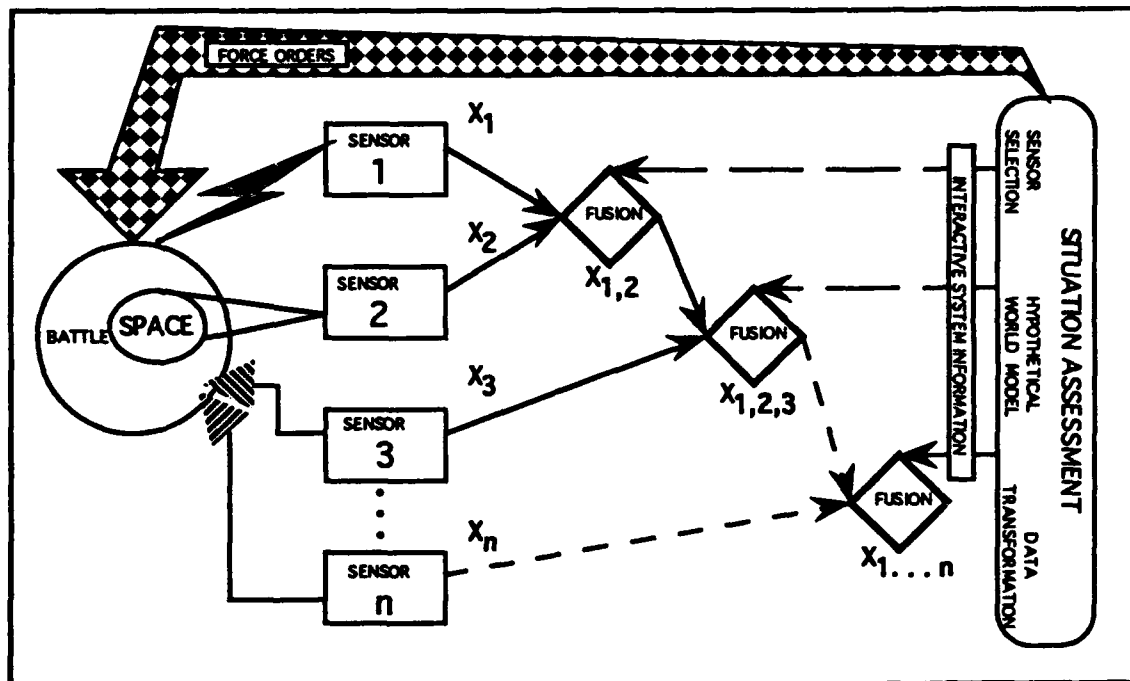


Figure IV-5: General Pattern of Information Fusion (after Luo & Kay, 1988)

The transformation from lower to higher levels of representation as the information moves up through the structure is fairly common among most fusion structures. At the lowest level, raw sensory data enters the sensors and is transformed into information in the form of a signal. Not represented in the diagram might be a horizontal line into node 2 or 3 that would represent non-organic, or national level information or intelligence that is already somewhat fused/processed/ finished that becomes further fused relative to the user's pull criteria and specific, definitive battle space environment. *As a result of a series of fusion steps, the signal is transformed into progressively more abstract iconic or symbolic representations.* It is these representations that have value; the amount or magnitude of a vector of the symbol now becomes an issue for the cognitive scientist or

knowledge engineer to examine — designing the system interface to allow for the best human-system performance possible.

The functions indicated along the right hand side of Figure IV-5 are but a few typically used as part of the fusion process. "Sensor Selection" can select the most appropriate single or group of sensors to use in response to a dynamic environment. Sensory information can be represented within the "world model,"⁷ and the information from different sensors may need to be "transformed" before it can be fused or represented in the world model.⁸

Figure IV-6 represents an expanded and fairly complete methodology for sensor fusion for a generic military command and control system. It may be viewed as a compilation of the previous systems and introduces the concept of user interfaces explicitly within the situation assessment module. The operation of this system can be divided into four steps of a feedback loop. First, a multitude of sensors and information sources collect and forward information from the battlespace to the fusion subsystem. The functions within this subsystem integrate and fuse target data so target events can be located and identified. The fused information, representing the current situation, is then sent to the decision support subsection where it is used to create, analyze, and rank alternative courses of action. A human commander completes the feedback loop by selecting courses of action or interacting with his system which may then change his environment.

⁷The idea of a "world model" is an integral part of the KOALAS concept and is discussed in further detail in Chapter VI, KOALAS. Essentially, a world model is a simulation or representation of the battlespace with which the warrior can interact. He can "game out" the results of sensor tasking and force orders.

⁸This might be as easy as time synchronization, analog to digital conversion, or translating data into a common computer language representation.

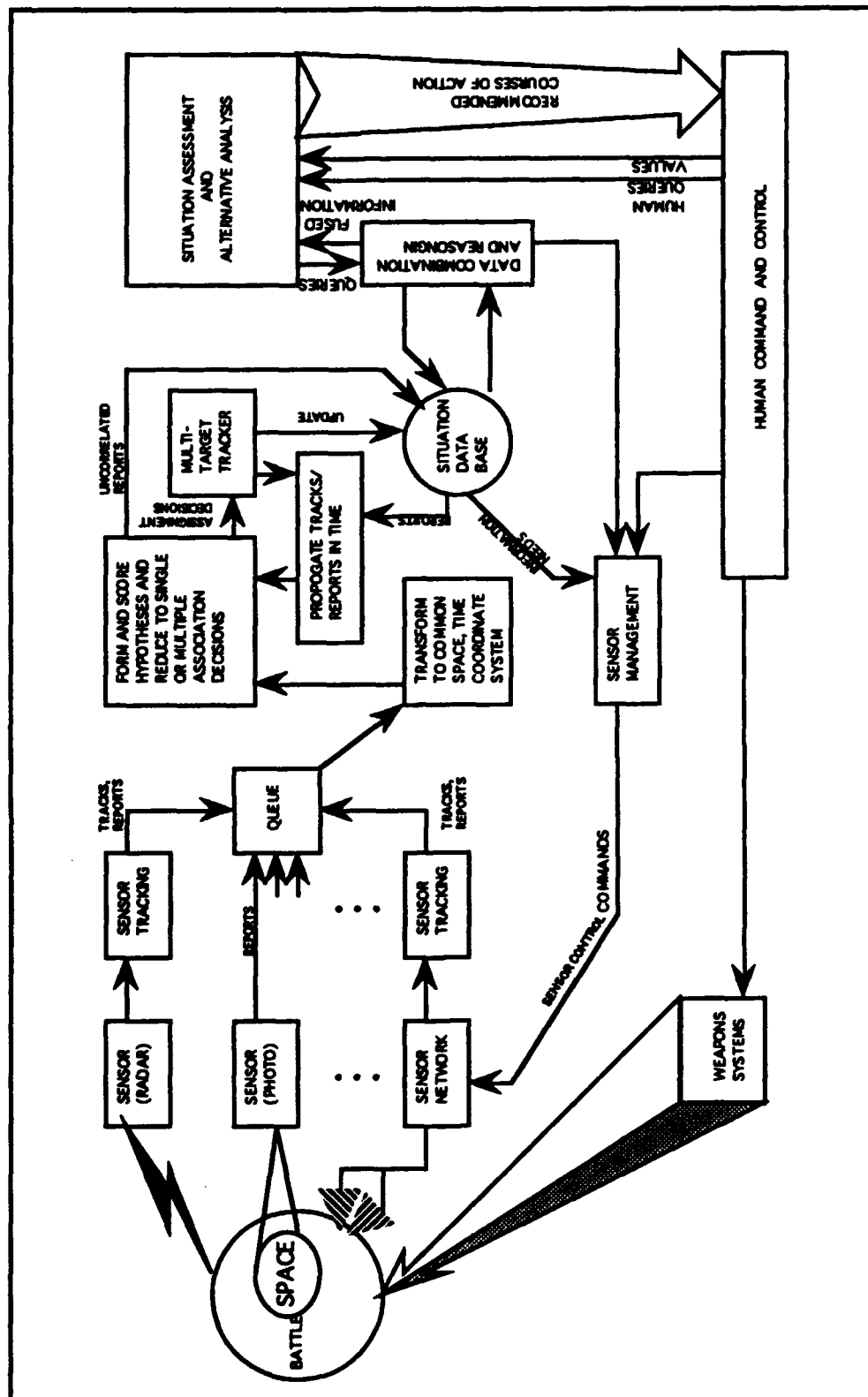


Figure IV-6: Military C2-Information Fusion System (after Luo and Kay, 1988)

The key feature here is the specific address of the role of the human commander within the system. The system initiates operation with a query from the human commander to the decision support subsystem for recommended courses of action. This query would be an adjunct to ongoing queries or requests for information from his system. This is a manifestation of the "user pull" feature of the Copernicus and C4IFTW architectures.

Using certain key parameter values supplied by the human commander and the systems' assessment of current situation, the decision support subsystem analyzes alternative courses of action, possibly querying the multisensor integration and fusion subsystem for additional information, to select those actions to recommend to the human commander. This is a manifestation of the KOALAS concept which increases the effectiveness of the system and the operator by exploiting human inductive processes. The human commander can then either select one of the current recommended actions, query the system for additional information, or implement his own decision. Obviously, the human commander can always make the final decision, certain routine or time-critical actions can automatically be determined by the system. This is a direct link with the KOALAS notion of "intelligent control."⁹

C. BENEFITS OR ADVANTAGES OF FUSION

At this point, it is clear what the fusion process is and what some of the problems associated with accomplishing sound information fusion. It becomes important to understand what a few of the "payoffs" are relative to system and operator performance. These advantages are addressed below.

⁹Intelligent control refers to attempts to aid human cognitive performance by interlacing human and computer reasoning and is discussed in more detail in Chapter VI, KOALAS.

1 . Accuracy

Information concerning a feature or group of dependent features in the environment can be obtained with greater accuracy. This follows the notion of redundancy whereby redundant information from multiple sensors can serve to increase the accuracy of the fused information by reducing the overall uncertainty of the information.

2 . Precision

Information concerning a feature or group of dependent features in the environment can be obtained with greater precision. Multiple sources may be cross-referenced and cross-linked which will establish a better baseline concerning the disposition, orientation, and deployment of enemy forces.

3 . Reliability

Information concerning a feature or group of dependent features in the environment can be obtained with greater reliability. Multiple sensors serve to increase the reliability of the system in the case of error or failure.

4 . Synergism

Information concerning additional independent features can be obtained. The synergism with which tactical operators are primarily concerned is the effort to reduce or resolve ambiguity, to perform quick and effective target discrimination, and to discern enemy intent. It is this notion of synergistic value of information derived from sensor fusion and applied within a situational awareness framework that is the focal point of the KOALAS initiative. KOALAS is none of these; but rather, it encompasses all of them. Hence, complementary information from multiple sensors allows independent features in the environment to be identified by the system.

5 . Cost

Information is obtained at a lesser cost when compared to the equivalent information from a single sensor system. Here, the argument revolves around the notion

that to obtain equivalent information value from a single sensor is prohibitively expensive when viewed in the context of information value available from fused information.

6. Time

Information about the environment can be obtained in less time. More timely information may result from the increases in sensor operation speed resulting from technology advances or the processing parallelism in the fusion process. In other words, viewing component information at the same time with inferred value (parallel) or viewing information one piece at a time (serial).

7. Performance

An increase in performance relative to the value of information and not necessarily individual sensors. Fused information displays such performance gains as higher quality, accuracy, and timeliness versus like information taken from numerous and varied sources that must be integrated manually over time.

8. Extended Spatial Coverage

Information fusion provides the warrior the opportunity to view the battlespace in a concise and comprehensive fashion. Integrated information removes the onus from the warrior to accommodate this requirement by devoting untold man-hours to this labor. In turn, his attention can then be appropriately applied to a broader and deeper view of his battlespace.

9. Survivability

The increased reliability, accuracy, performance, and timeliness of the fusion process serves to increase not only the survivability of the troops using the information, but the system which provides the fused information as well. Commanders can manage their forces better as a result of this fusion process. Better management and leadership implies better combat results which, in turn, implies a higher probability of survival for both the warriors and the systems they use.

10. Improved Detection

Simple probability theory and common sense would predict that the probability of detection against a target increases with an increase in the number of detection devices employed against that target. Similarly, since the value of the information derived from fusion increases, it may hold that new or unexpected targets may fall into the detection envelope.

11. Reduced Vulnerability

The fusion process reduces the effectiveness of enemy countermeasures directed at the warrior or his information. As a direct result of the fusion process, a system of sensors or information sources will not be degraded by enemy countermeasures whereas a single or a few independent sensors or sources may be effectively neutralized by enemy actions.

12. Robust Performance

Essentially, the fusion process permits an increase in virtually all nominal performance measures with no detractions. This robustness in quality information and system performance provide increases in the effectiveness of the commander and his troops in the battlespace. The fusion process provides clear, unambiguous, precise, accurate, and timely information felt across the entire battlefield. Fused information is vigorous in nature and powerful in content.

13. Increased Dimensionality

This notion is similar to synergism. Fused information provides a synergistic impact across more (number) and diverse (broader and deeper) dimensions of the battlespace. The impact of fused information will not be only on the deployment of forces for a current tactical situation, but, as an example, more completely using the results of yesterday's conflict to tomorrow's advantage.

14. Increased Coordination

Coordination improves the economy of military effort by reducing duplication and the likelihood of self-inflicted losses from accidents (friendly fire). Additionally, coordination implies the ability to simultaneously employ more troops of a greater diversity against the enemy across multiple fronts.

15. Increased Synchronization

Poor coordination and timing (synchronization) can dissipate lethal energy and negate whatever potential synergism may be realizable. Information fusion allows the commander to increase his efforts of coordination and the effectiveness of his timing thereby achieving greater synchronization.

E. HUMAN OPERATOR CONTRIBUTIONS

No discussion of fusion methodology, systems, problems or advantages would be complete without a nod toward the human factor. The human factor will continue to arise throughout this discussion simply because it is the focal point of the effort — why it is important to account for the human operator in the system's design. In this case, the human operator is perhaps the best model upon which to compare the salient features of any fusion algorithm, paradigm, or system. Generally speaking, while we may not be able to fully or completely understand how humans fuse data as well as they do, given several chassis limitations, they are quite adept at it. Humans attribute meaning to their experienced world, struggling to make sense of what they perceive. Based on these perceptions and interpretations, humans evaluate intentions and take action. Two specific instances of human excellence at fusion are discussed below. While this list is not complete, it will hopefully serve to illustrate that the original model is not half bad, but like all things, can be improved upon.

1. Flexible Body of Knowledge

Humans go through life compiling a huge working library and memory of perceptions, feelings, facts, figures and other knowledge memorabilia. Taken in isolation, perhaps an insignificant conundrum of trivia. Taken wholly out of context and in some magical, as yet unexplainable, morass of interconnections, deductive and intuitive sense can be made out of seemingly unrelated phenomena when applied to a specific situation. This flexible body of knowledge is the subject of one area of study, Expert Systems.

2. Information Modality

Information modality pertains to the ability to make sense out of physically or phenomenologically unrelated and dissimilar sensory perceptions. For example, the combination of *sight* and *sound* can aid in the identification of an unknown as well as provide a "sense" of what the intent is. A W.W.II German Stukka dive bomber was not only an easily distinguishable airframe, but when it intended to "kill," it made a distinctly distressing and piercing "scream."

F. REQUIREMENTS FOR SUCCESSFUL FUSION

Given that the general process of fusion is understood, and that the advantages and problems associated with existing and proposed fusion methodologies are at least recognized if not entirely comprehensible, then all that remains to ensure that fusion is properly focused on mission tasks and the user within the Copernican/ C4IFTW frameworks is to consider what marks success. The following points are compiled from multiple sources, principally, Luo and Kay (1988), Naylor (1987), Comparato (1988), and Lakin and Miles (1987).

- Fusion is a system and process that lets a human operator control and monitor data from the sensor bank and draw appropriate conclusions.
- Fusion is a hard-wired semiautomatic, semiautonomous system which serves to reduce human cognitive load and increase human cognitive understanding.

- Fusion will employ automatic systems that can operate a variety of sensors, employs AI techniques to detect objects of interest, integrate, interpret and classify their data, and have the flexibility to adapt to changing situations.
- Fusion must be fault tolerant. Sensors can operate independently of one another thereby decreasing the reliance on one source and allowing for reduced fidelity as a result of some sensor, device, system, or architecture error. The information available is what is important. Information content is the bailiwick of the assessment phase...they are separable but not independent. Faults at sensor nodes will incur failure, but the system as a whole will continue operating.
- Fusion must be adaptive to the threat environment. Sensor fusion must be responsive to quickly changing battle conditions.
- Fusion must specify sensor or information source characteristics, properties, and output in terms of physical laws subject to uncertain sensor or source geometry.
- Fusion must develop or support a methodology for sensor or source data/information analysis and compensation techniques.
- Fusion organization must be able to direct sensors to fulfill specific roles.
- Fusion management must provide greater tolerance for sensing device failure, and generation of appropriate control tasks.
- Fusion must successfully and effectively integrate and accommodate the user.
- Fusion processes support dynamic reconfiguration of the sensor systems and information sources.
- Fusion must reduce complexity through shared resources.
- Fusion must allow real time monitoring of sensors.
- Fusion must reduce human cognitive loading and increase human cognitive efficiency.
- Fusion must increase P_{kill} against the enemy.
- Fusion must increase $P_{survival}$ for own forces.
- Fusion must increase mission effectiveness.

G. SUMMARY and CONCLUSIONS

The effects of fusion will be felt and discerned by the operator at some sort of integrated display. Current technology mandates some sort of Video Display Unit; the

future holds such things as synthetic environments and virtual reality applications which are user-interface dependent on technology. The popularized "cyberspace" vision holds that human ingenuity will move beyond or even transcend the limits of technology to where the operator can move along the digital highways of the information world viewing, reviewing, selecting, and fusing when, where and how he sees fit, all at the speed of human intuition. The focus of this thesis is not necessarily how fusion happens or the algorithms used, but a look at the results of effective fusion and how to make the operator and the system more effective regardless of the black box internals or the architecture externals. KOALAS represents an information handling and processing taxonomy that enhances the human operator's intuitive feel for the situation thereby permitting a hypereffective sensor or information fusion capability. Information fusion is an integral part of developing and nurturing this intuitive capability.

There is nothing magical or even new about information fusion— every commander can tell you why fusion is important. However, the new technologies available make the presentation metaphor a dynamic variable, not to mention the sheer volume of information that will be required to be fused. There may be as yet unrealized or unforeseen value, gains, or detriments as a result of the volume of information to which the world is and will be subjected. Finally, this information is the key to sound situational assessment, which will be discussed in further detail in Chapter V.

V. SITUATION ASSESSMENT

*It's not what we don't know that gives us trouble.
It's what we know that ain't so.*
- WILL ROGERS

As indicated by Figure V-1, below, this chapter will discuss some of the broad issues concerning the notion of situation assessment relative to human decision making, information processing, and intuition.

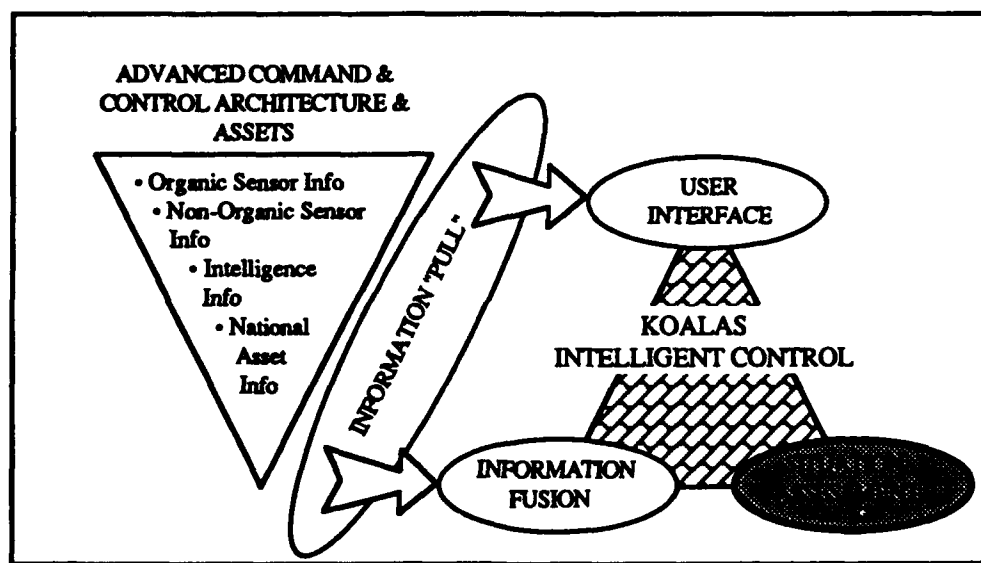


Figure V-1: Situation Assessment within C2

One of the most critical and challenging activities any command can undertake is to construct and maintain the best possible assessment of the tactical situation within the area of responsibility or operating area in general. In principle, this would include locating, tracking, and classifying all objects contributing to that situation, and doing so quickly enough to react to any aspects which may pose an immediate threat to the commander's forces. More importantly, the focus is most intense within the realm of discerning the

"intent" of an object or contact. Often, this perception or intuitive "feel" of intent is the key factor which delineates an unknown contact as "hostile" or "friendly" and if "hostile," is the key point in ordering forces to engage.

A. DECISION MAKING

Arguably, the ultimate measure of effectiveness by which to judge the advanced C⁴I architecture initiatives introduced in Chapter II is how well they support the warrior in making his decisions. In essence, command and control is the fruit of the decision making process. Decision making "... is a complex process by which people evaluate alternatives and select a course of action. The process involves seeking information relevant to the decision at hand, estimating probabilities of various outcomes, and attaching values to the anticipated outcomes." (Sanders and McCormick, 1987, p. 63) Interestingly, people seem generally unaware of how they make decisions. Perhaps this stems from an equally prevalent lack of awareness on how they seek information. Often times, they are unable to explain why they prefer one alternative to others. Principally, individuals care little for the quality of their own decision making process and care much about the inability of others to make decisions. In an effort to simplify the discussion, the notion of decision making will be broached in terms of three models - normative, descriptive, and prescriptive. (Smith and Sage, 1991)

1. Normative

The normative model of decision making describes what decisions a person should make if they follow certain axioms. Sometimes, this is viewed as a quantitative model of decision making based on a hypothetical human in a hypothetical situation following axiomatic behavior. This approach attempts to explain how people should make decisions if they wish to follow accepted laws of behavior. The normative approach comes

from decision theorists and is often characterized as a rational approach to decision making. (Smith and Sage, 1991, p. 449, 459)

2. Descriptive

The descriptive model attempts to illustrate the manner in which a real person goes about making a decision in a variety of situations. This process is often flawed and generally personalized to a specific individual. Descriptive models of decision making generally result from psychological studies. These studies are essentially interested in how a person actually makes a decision in the real world and to what extent the individual's decision process is compatible with rational decision models. (Smith and Sage, 1991, p. 449, 459)

3. Prescriptive

The prescriptive model attempts to modify the normative model to fit a real human in a real decision situation. These models may be thought of as the result of a systems engineering approach to improve the decision making process through the use of information technologies. These models attempt to permit "good" decisions to be made even if information on alternatives or situation hypotheses are incomplete. (Smith and Sage, 1991, p. 449, 459)

4. Four Types of Decisions

Regardless of the specific decision process or combination used¹, the type of decisions commonly made may be easier to place into context. Sage reports four types of decisions:

- **Strategic Planning Decision:** decisions related to choosing highest-level policies and objectives, and associated resource allocations.

¹The discussion relative to decision methodologies is by no means complete. It is intended to provide a *simple and concise* conceptual and contextual frame of reference for the reader.

- **Management Control Decisions:** decisions made for the purpose of assuring effectiveness in the acquisition and use of resources.
- **Operational Control Decision:** decisions made for the purpose of assuring effectiveness in the performance of operations.
- **Operational Performance Decisions:** day-to-day decisions made while performing operations. (Sage, 1991, p. 2)

For purposes of discussion, the latter two are generally more pertinent to the majority of warriors because they interact with their battlespace.

It is generally believed that operational decisions are made with more frequency and are associated with less consequence or risk than either management or strategic decisions. However, operational decisions may be characterized as possessing a fair amount of immediacy about them. Generally, warriors at all levels are rarely, if ever, afforded the luxury of having either the time or the support resources — facilities, manpower, equipment, etc. — to assist them in making operational decisions. The decisions made at the warrior level are often times based on a "sense" or perception of what *is* happening in the battlespace and a belief or prediction of *what is about to happen* in the battlespace. These "heat of battle" decisions are not easily "fitted" into one of the above three categories of decision making methodologies. In fact, "methodology" implies almost a structured, rigorous, or even scientific approach to making decisions. Rather, these operational decisions are often made based on a "hunch," or "gut-feeling" of what is happening — in short, intuition. This notion of human intuition is discussed in further detail later in this chapter.

5. Situation Assessment

"The decision process begins with an assessment of the situation and hence the ability to make an accurate and pertinent situation assessment is integral to an effective decision process." (Smith and Sage, 1991, p. 449) Simply put, situation assessment is the process of identifying and defining the problem. This thesis argues that a warrior's

situation assessment can be enhanced by augmenting his innate intuitive judgment by accomplishing sound and accurate information fusion resulting from the transition to an information pull doctrine supported by advanced technologies as implemented in the advanced C⁴I initiatives currently tabled. A brief overview of the human decision making process has been discussed. Situation assessment and human intuition will be developed in detail later in this chapter. Appropriate attention must now be directed to the impact of information within this archetype.

B. INFORMATION IMPACT

As noted previously, decision making is fundamentally dependent on seeking and processing information relevant to the decision at hand. The advanced C⁴I architectures will place the onus of information seeking back where it belongs - on the warrior. Information pull, as discussed in Chapter III, is an indication that the C⁴I architectures of the future will indeed support the warrior's decision making process. Similarly, decision making is dependent on the warrior's ability to process this information subject to human cognitive limitations. This section will address some issues relevant to information seeking and processing pursuant to establishing linkage with situation assessment.

1. Information Variables

Information is viewed in relation to the battlespace within which it resides. As such, there is a high degree of uncertainty and variability associated with this information. Additionally, this information is task dependent; that is, the warrior will seek the information he feels is relevant to his mission statement and battlespace objectives. As reported in Sage (1991), there are essentially eight information relevant variables pertaining to any given decision making or situation assessment process:

1. *Inherent Accuracy of Available Information.* Operational control situations will often deal with information that is relatively certain and precise. The information in strategic situations is often uncertain, imprecise, and incomplete.²
2. *Needed Level of Detail.* Often very detailed information is needed for operational-type decisions. Highly aggregated information is often desired for strategic decisions.³
3. *Time Horizon for Information Needed.* Operational decisions are typically based on information over a short time horizon, and the nature of the control may be changed frequently. In contrast, strategic decisions are founded on information and predictions based on a long time horizon.
4. *Frequency of Use.* Strategic decisions are made infrequently, although they are perhaps refined fairly often. Operational decisions are made quite frequently and are relatively easily changed.
5. *Internal or External Information Source.* Operational decisions are often based on information that is available internal to the organization, whereas strategic decisions are much more likely to be dependent on information content that can only be obtained external to the organization.⁴
6. *Information Scope.* Generally, operational decisions are made on the basis of narrow-scope information related to well-defined events internal to the organization. Strategic decisions are based on broad-scope information and a wide range of factors that often cannot be fully anticipated prior to the need for the decision.
7. *Information Quantifiability.* In strategic planning, information is very likely to be highly qualitative, at least initially. For operational decisions, the available information is often highly quantified.
8. *Information Currency.* In strategic planning, information is often rather old, and it is often difficult to obtain current information. For operational control decisions, very current information is often needed.

²This notion was similarly addressed in Chapter IV, Fusion. The relative scale of operational uncertainty and strategic certainty is precisely that - relative. In this context, certain and precise information associated with operational control situations may mean that the sources of information are simply more immediate, closely linked, and within the operational control of the battlefield commander and subject to his feedback. Additionally, strategic decisions are generally farther reaching in scope and not considered within the sphere of a battlespace.

³Part and parcel to the idea of information fusion addressed in Chapter IV, Fusion. The information detail is something that will be established by the warrior via the information pull feature of the advanced C⁴I architectures by interacting with the architecture's capabilities presented in Chapter III, Information Pull and Technology.

⁴A key feature that may not be clear is that the advanced C4I architectures intend to obviate or even negate this information variable. The access features of transparency and seamless operations addressed in Chapter II, Advanced C4I Architectures, will ensure that the warrior gets any and all information that exists.

These information variables help to determine the quality of the information upon which the warrior will assess his battlespace. (Sage, 1991, pp. 4-5)

2. Information Processing Realities

Sage presents several fundamental characteristics pertinent to understanding and aiding the human situation assessment process. These may be thought of as information processing realities. These are but a few items and broad in scope.

- Humans have extensive wholistic (intuitive affect, reasoning by analogy, etc.) information-processing abilities. (Sage, 1991, p.16, 296)
- Humans use potentially definable and identifiable judgmental guidelines, perspectives, and rules that are more or less appropriate, depending on their applicability to the task at hand. (Sage, 1991, p. 16, 296)
- As the amount of information imperfection increases, there will exist a much greater need for cooperative interaction among the various human, technological, and organizational elements that comprise a task. (Sage, 1991, p. 19, 298)
- The majority of studies of human decision making, especially in organizational settings, shows that people rarely concentrate on one problem at one time but generally consider, in a simultaneous (often nonsystematic and parallel) manner, a diversity of problem-solving situations. (Sage, 1991, p. 20, 298-299)
- Human performance may suffer when the task requirements suggest performance of several subtasks, often in diverse stages of completion, in parallel. (Sage, 1991, p. 20, 299)
- Humans are limited in their unaided ability to process aleatory, or statistical, information. (Sage, 1991, p. 20, 299)
- Humans often reason quite well based on epistemic and evidential information. Confirmation and denial rules, while potentially very flawed from the strict viewpoint of mathematical logic, often yield very acceptable judgments and often represent the only types of information available for judgment. (Sage, 1991, p. 20, 299)

These realities, both pro and con, are important for the warrior to keep in mind for several reasons. First, an *appreciation* for the simple fact that these realities exist will aid the warrior in thinking about the decision environment in which he must function. Second, an *understanding* of these realities enables the warrior to seek and process his battlespace information more effectively. Finally, an *acceptance* of these realities enables the warrior to

be adaptable and to interact and interface with his battlespace to his advantage. Appendix B provides additional information on human decision making models and information processing biases.

3. Information Processing Consequences

Similar to the above discussion, the consequences of limited human information processing capacity as discussed by Hogarth are presented below.

- Perception of information is not comprehensive but selective;
- Since people cannot simultaneously integrate a great deal of information, they process information in a predominantly sequential manner⁵;
- Information processing is necessarily dependent upon the use of operations that simplify judgmental tasks and reduce mental effort; and
- People have limited memory capacity. (Hogarth, 1987, p. 208)

These consequences, in addition to the realities presented above, become especially important relative to the warrior attempting to interface with his battlespace. His situation assessment process will hinge on his ability to minimize these information consequences while working within his information realities.

Stemming from this limitation and attributable to man's adaptability is the fact that people do not generally submit to their environment, at least passively. Most decision processes, information processing, and situation assessments require some degree of control over the environment resulting in people acting on the environment — in the case of the warrior, this would be the essence of command and control.

C. SITUATION ASSESSMENT PROCESS

As mentioned previously, the decision process begins with an assessment of the situation. By extension, this assessment is based on human judgment. These judgments

⁵Recall the discussion concerning parallel processing and connectionism presented in Chapter III. Sequential processing refers to how people collect and synthesize multiple sources of information. Parallel processing refers to how people assimilate and grasp information after it has been gathered and/or presented.

are made intuitively, without reasoning and on an almost instinctive level. (Hogarth, 1987, p. 1) However, in light of the increasing complexity, rapidity of change, and growing unfamiliarity of circumstance, Hogarth argues that the intuitive process that has served the human race well in the past is inadequate to meet the demands of the future.

The intuitive judgments alluded to above are based on information that has been processed and transformed by the human mind. Recent work in the field of cognitive psychology has produced some firm conclusions regarding the ability of man as an information processor. One, people have limited information processing capacity. Two, people are adaptive. It may be argued that it is precisely this capacity "limitation" which portends adaptability thereby enhancing intuition.

1. Intuition

The notion of intuition is perplexing. Indeed, one is hard pressed to explain exactly how intuition "happens." Based on practical experience, it seems that intuitive decision making is the mainstay of experienced decision makers — those often referred to as "experts." There may be an argument that supports the idea that the more appropriate role of a computer expert system is not to capture an expert's knowledge, but rather, to capture an expert's intuition. Where Hogarth seems to doubt the impact or validity of intuition or intuitive decision making in the future, Morris, as presented in Sage and Smith, "conjectures that it is the abilities of the decision maker to improve the intuitive capabilities as opposed to the logical/ mathematical capabilities that are the more important and useful for the decision maker." (Smith and Sage, 1991, p. 454)

It is difficult to "get a handle" on just what is meant by the use of the word "intuition." Kahneman and Tversky define the terms *intuition* and *intuitive* relative to how they are used:

First, a judgment is called intuitive if it is reached by an informal and unstructured mode of reasoning, without the use of analytic methods or deliberate calculation.... Second, a formal rule or a fact of nature is called intuitive if it is compatible with our lay model of

the world.... Third, a rule or a procedure is said to be part of our repertoire of intuitions when we apply the rule or follow the procedure in our normal conduct. (Kahneman and Tversky, 1982, p. 494)

Similarly, human intuition has been represented as an inductive process. It has been presented as the result of various cognitive strategies. The notion of human foresight and prediction is often associated with intuition. Glass, Holyoak, and Santa have described intuition as a result of prototype matching, or more generally, a result of a representativeness strategy of decision making and situation assessment. (Glass, Holyoak, and Santa, 1979, p. 389) Kahneman and Tversky suggest that intuitive predictions are generated based on a simple matching rule and are nonregressive⁶ in nature. (Kahneman and Tversky, 1982, pp. 416-417) Hogarth makes an amplifying case that intuitive predictions are based largely on an individual's causal understanding of the world. (Hogarth, 1987, pp. 40-41, 160-162)

Intuition, then, may stem from the simple fact that it is an intrinsic human ability to compensate for limited information processing capability. Indeed, this information handling limitation means that warriors must accept the battlespace as probabilistic. Hogarth states, "... the source of uncertainty lies within us [humans] rather than in the environment." (Hogarth, 1987, p. 33) There may even be a cohesion or coupling between intuition and this notion of judging probable cause. Hogarth continues, "Nonetheless, people do have strong intuitions concerning the presence or absence of cause in particular circumstances. Moreover, these form the bases of judgments of probable cause." (Hogarth, 1987, p. 41)⁷ There are strong implications in the value and power of

⁶In essence, intuitions result from a cognitive model of the world; this model is not influenced by intuition.

⁷Hogarth provides four types of considerations that may affect probable cause judgments. The author believes they may be equally attributable to human intuitive judgments as well. In the interests of brevity they will be listed here: (a) the causal field or context in which such judgments are made; (b) the use of various imperfect indicators of causal relations called "cues-to-causality"; (c) judgmental strategies employed by combining the causal field with the "cues-to-causality"; and (d) the role of alternative explanations in discounting the strength of particular causal beliefs. The reader is invited to consult Hogarth, p. 41, for further amplification.

tapping this human judgmental reserve. Relative to the warrior assessing his battlespace, intuition and/or judging probable cause is intimately embedded in the idea of determining "hostile intent" based on uncertain information that is sampled from a complex and dynamic environment.

Given that intuition is a large part of the decision making and situation assessment process, it is important to link the significance of the preceding chapters to this discussion. According to Smith and Sage, there are two major complicating factors associated with situation assessment. One, the sources of information that describe the battlespace may have imperfections so that the information may be erroneous, fuzzy, or generally uncertain. This is the foundation of the argument for information fusion. By employing fusion schema, this information uncertainty may be reduced. Two, "... the situation assessment process should provide the decision maker with only the information required for that particular decision maker in that particular context to generate and select the proper decision alternative." This is, of course, a fundamental concern addressed by the implementation of user pull within the advanced C⁴I architectures. User pull avoids irrelevant or deficient information conditions because the warrior's information is defined in terms of his battlespace. (Smith and Sage, 1991, p. 450)

2. Situation Assessment Functions

It is now readily apparent that sound and accurate situation assessment are supported by information fusion and user pull. But what is "situation assessment" exactly? According to Noble, as reported in Smith and Sage, situation assessment is made up of the following functions:

- An estimate of the purpose of activities in the observed situation,
- An understanding of the roles of the participants in these activities,
- Inferences about completed or ongoing activities that cannot be directly observed, and

- Inferences about future activities. (Smith and Sage, 1991, p.450)

These are all functions that occur continuously by a warrior in evaluating his battlespace. Particular attention ought be paid to the last two bullets concerning inference. Again, according to Smith and Sage, situation assessment is accomplished by performing a series of inference tasks. Each task is supported by interacting knowledge sources and processing resources. Advanced C⁴I architectures support this goal of situation assessment by enabling the warrior to see his battlespace more completely by providing a better understanding of an uncertain situation. (Smith and Sage, 1991, p. 451)

3. Situation Assessment Process

Functionally, situation assessment may appear rather ... simple. In action, however, good situation assessment is subject to the vagaries of the decision maker or the warrior. Before some of these limiting factors are introduced, the actual situation assessment process is discussed. According to Smith and Sage (1991), situation assessment consists of eight steps and is represented in Figure V-2.

If nothing else, it becomes important to note that the crux of the situation assessment process is the gathering of information. More appropriately, the display of pertinent and accurate information. As noted previously, gathering the information will be a technological solution. Presenting the information will be the foundation of the human-information interface. This interface, then, will be the tool by which the warrior begins, conducts, and completes his assessment of the situation. Smith and Sage present three types of errors that may result while performing situation assessment:

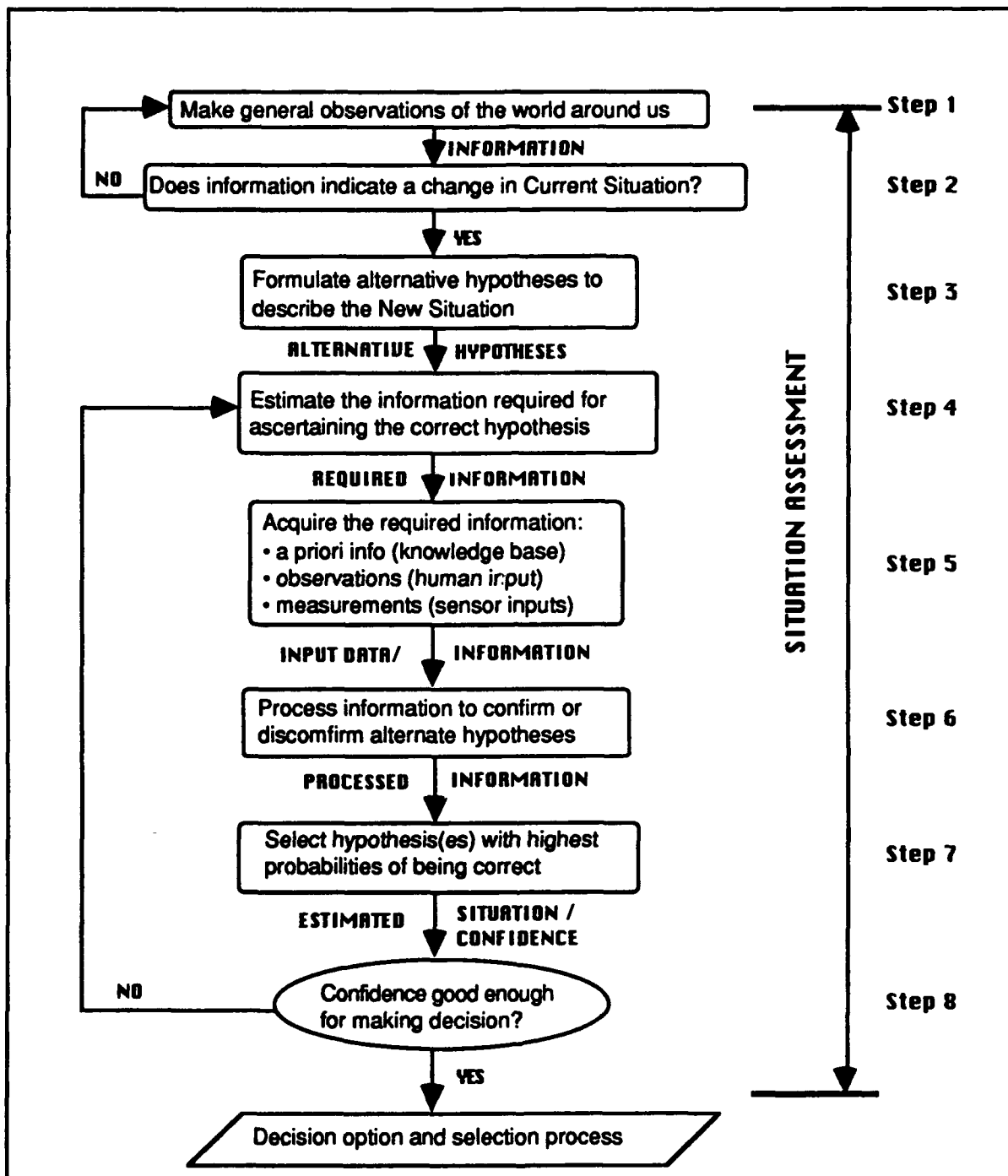


Figure V-2: Conceptual Illustration of Situation Assessment (after Smith and Sage, 1991)

- Type I Errors — errors that result from incorrectly assessing there is a problem when there is no problem (false alarms);⁸
- Type II Errors — errors that result from incorrectly assessing there is no problem when there is a problem (misses);⁹ and
- Type III Errors — errors that result from correctly assessing there is a problem, but incorrectly identifying the problem.¹⁰ (Smith and Sage, 1991, p. 453)

A problem may be viewed as a difference in what is occurring in the battlespace and what the warrior would like to have occur. Situation assessment serves to help identify this "delta," collect and process relevant information, generate and review alternative courses of action, and make a decision to implement one or more of these courses of action to reduce, minimize, or eliminate this gap. Information fusion and information pull serve to detect this gap quicker and make alternative selection more effective and efficient.

4. Dynamic Situation

In the warrior's battlespace the issues associated with situation assessment will be dynamic. This may be for a variety of reasons, but principally and simply because armed conflict is rarely static. It would be a difficult argument to make that the "clash of swords," or the "rock-n-roll" of semi-automatic assault rifles is a static process. By default, then, the warrior's situation assessment process will revolve around a battlespace or combat environment that is in a perpetual state of flux. Brehmer, as reported in Smith and Sage, characterizes a dynamic situation as follows:

⁸Recall the discussion of the *USS Vincennes* - Iranian Airbus Incident in Chapter IV, Fusion. This is an excellent example of a Type I Error. The CIC team incorrectly assessed that the inbound air contact (Commercial Airbus) was a hostile warplane - a problem - when there was in fact, no problem or threat.

⁹Recall the discussion of the *USS Stark* - Iraqi Mirage incident in Chapter IV, Fusion. This is an excellent example of a Type II Error. The CIC team in the *USS Stark* incorrectly assessed that there was no problem with the correctly identified Iraqi Mirage when, in fact, the Iraqi warplane was a threat, or a problem.

¹⁰The incident at Three Mile Island nuclear power plant is an excellent example. Here, it was correctly assessed that a problem did exist, but the operators were unable to diagnose or identify what the nature of the problem was based on available, conflicting, and uncertain information.

- It requires a series of decisions;
- The environment changes both spontaneously [and] as a consequence of the decision maker's actions;
- The time element is critical; it is not enough to make the correct decisions and to make them in the correct order, they also have to be made at the correct time. (Smith and Sage, 1991, p. 456)

Additionally, the process of situation assessment that centers on a dynamic battlespace possesses the following attributes:

- Complexity refers to the number of goals of the system, the number of processes that must be controlled to reach the system's goals, and the number and descriptions of the means available by which the processes can be controlled.
- Delays, such as information system delays or delays in the command system, may or may not affect the processes and the system goals.
- Characteristics of the processes and the means can affect the controllability of the processes.
- Rate of change of both the process to be controlled and the means may affect the controllability of the system by the required nature of feedback information of the situation.
- Delegation of decision-making power by imposing a hierarchical organization for control is often used. Control can be centralized or distributed.
- Feedback quality can affect the ability of the commander to perceive the situation clearly.
- Probabilistic or deterministic aspects, or more generally the extent to which system responses and performance are predictable in advance.

It is the simple acceptance of the dynamic nature of the warrior's situation assessment incorporated into the design of his user-technology interface that will enable him to counter the chaotic effects often associated with the battlespace. (Smith and Sage, 1991, p. 456)

5. Tasks of the Situation Assessment Process

The situation assessment process described above consists of several tasks as presented by Smith and Sage. These are presented in Figure V-3 as well as summarized below.

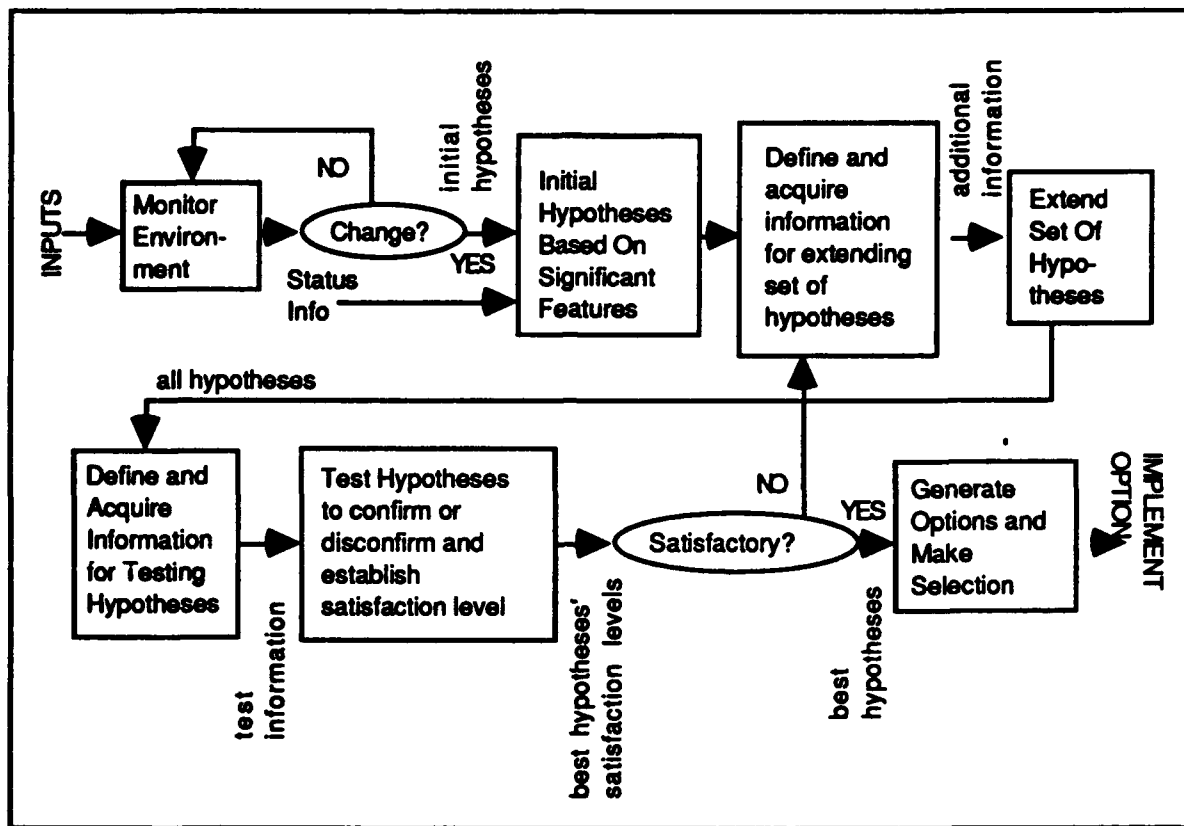


Figure V-3: Tasks of the Situation Assessment Process (After Smith and Sage, 1991)

- **Monitor the environment.** If there is a change then begin generating situational hypotheses. The environment is monitored by collecting data or information from sensors and sources. This is an extension of the information pull and information fusion subsets of the advanced C4I architectures. The change here is the same as the "delta" referred to earlier in this chapter and is referenced to a priori defined parameters, much like P2E2Is.
- **Define a basic set of initial hypotheses** that can explain the situation relative to the perceived change. These hypotheses will be dependent on such items as the user's perspective, decision style, and experience level.
- **Given the initial hypotheses and the status information,** define the current and future information requirements for extending and refining these hypotheses.
- **Extend the hypotheses set** by generating new or more refined and detailed hypotheses based on the situational development, evaluation, and analysis.
- **Define and acquire the information needed to confirm established hypotheses and quantify the satisfaction levels of remaining hypotheses.**

- Determine if any of the remaining hypotheses meet or exceed the minimum quantified satisfaction level. This represents the best hypothesis.

The value of this model lies in the identification of steps to accomplish situation assessment. In addition, it is based on seeking and processing the necessary information to perform situation assessment correctly. (Smith and Sage, 1991, pp. 456-457)

6. Ingredients of Situation Assessment

Smith and Sage amplify the process and tasks of situation assessment by providing the major ingredients associated with accomplishing situation assessment. Their discussion is summarized below:

- **Inputs.** The inputs to the assessment process are the data, information, and knowledge required for generating and testing the hypotheses. Referring to Figure V-3, the environment may be thought of the battlespace. This battlespace is comprised of own forces, enemy forces, and the physical environment encompassing these forces. Battlespace status information parameters are inputs as well and are defined a priori as the foundation upon which change is determined.
- **Models.** These are the paradigms used for defining and understanding the different aspects of the situation assessment process. For example, these would include the decision models addressed earlier in this chapter.
- **Inquiring Systems.** This may be thought of as the interface between the human and decision and situation assessment process. They may include the different ways of solving the problem, requesting inputs, seeking information, generating hypotheses, and developing alternative options and courses of action. This notion will be addressed later in Chapter VI, KOALAS, and is illustrated in Figure V-4. Notionally, this inquiry system consists of a user interfacing with a decision support system. This interface will be established using technologies discussed in Chapter III. The double loop learning is intended to modify the interface to make it adaptable and knowledgeable to dynamic situations.
- **User Perspectives.** These are the ways the decision maker may view the problem. Additionally, situation assessment nominally will include projecting the alternative ways an opponent will view a problem set as well as considering one's alternative views of the same problem set.
- **User Stress Levels.** These are the different behavioral responses used when encountering the problem set. These may be a function of seriousness or familiarity of the decision environment.

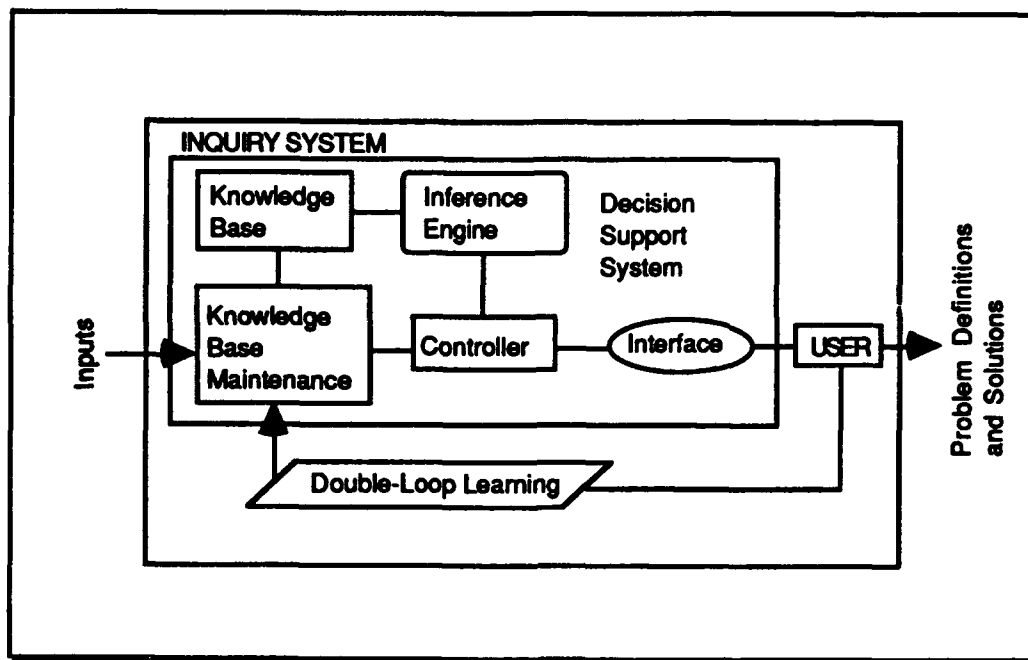


Figure V-4: Inquiry System (After Smith and Sage, 1991)

- **User Experience Levels.** These may be thought of the user's skill level. This is a natural aspect of each individual user and not changeable in the short term.
- **User Natural Decision Styles.** These are the broad continuum of typical ways of thinking about a problem. This is a function of personality, training, and education.
- **User Decision Strategies.** These are the different ways of generating and quantifying the alternative courses of action based on several factors — for example, the situation, the objectives, the risk analysis, available resources, the enemy's projected force deployment, available time, and a host of other parameters. (Smith and Sage, 1991, pp. 459-460 & 462-463)

The principal focus of this section necessarily needs to be on the inquiry system. While the other factors are important to the situation assessment process, they may, in a very broad sense, be viewed as inputs to the process. In simpler terms, these other phenomena are largely dependent on factors that are uncontrollable by the user or are a natural cognitive process of that individual. However, the inquiry system represents an idea that is a fundamental shift in the thinking about the situation assessment process. It is a culmination of the information pull and information fusion schema. It is the interface that

will allow the warrior to not only monitor and perform situation assessment, but enable him to have a higher degree of fidelity and control over his situation assessment. It will enable him to think better.

D. THE COST OF THINKING

Inevitably, success in terms of situation assessment goes beyond simple human information processing limits, chaotic environments, perplexing situation assessments, and complex control systems - the success lies in the thinking. Not necessarily in how, why, who, or whatever ... but in the simple act of thinking all by itself. The hard part in command and control is getting people to think. Telling or teaching them how, why, or what to think is easy. But getting them to *just* think is a feat of incomparable and virtually indescribable proportions. This is not leadership. This is not management. This is command and control. Thinking is a compromise between the demands of speed, necessity, accuracy, desire, precision, instinct, intellect, whim, and survival.

Hogarth (1987) presents an eloquent summary of some of the benefits and costs associated with thinking in order to perform situation assessment in support of a decision process. These are listed below in TABLE V-1:

TABLE V-1: THE COST AND BENEFITS OF THINKING (Hogarth, 1987, pp. 69-72)

BENEFITS	COSTS
• Thinking helps an individual control his actions thereby permitting some control over his environment. • Thinking helps clarify goals and preferences. • Thinking is self-perpetuating, that is, it leads to establishing the habit of thinking and of effective ways of thinking. Indeed, if one does not think about "easy" decisions, would they be able to think about difficult ones? • Thinking may lead to reformulating a problem and discovering alternatives that were not evident in the original perception of the task. • Thinking can lead to innovative ways of seeking information that will help perform situation assessment or decision making.	• Thinking highlights the uncertainties in a decision situation. • Thinking accentuates the uncertainties associated with the structure of a decision space. • Thinking makes explicit the "trade-offs" implicit in a decision. • Thinking requires individuals to process information. It has been established that humans possess limited processing capacity. Therefore, there are costs and tradeoffs associated with acquiring and processing information, performing situation assessment, and all culminating in the output of a decision.

E. SUMMARY

A broad and very general view of decision making, in terms of process characteristics and types of decisions has been presented. Subsequently, the role of information and pertinent attributes have been discussed. Finally, the nature of situation assessment within the human cognitive processes has been addressed. Throughout this chapter one overarching thought has been prevalent — information and information manipulation is the key to the situation assessment process. Information defines the decision problem space. Decisions are made on information available or intuited.

Information is sought, manipulated, processed, and mulled over. Information may be viewed as the commodity of situation assessment.

Hogarth (1987) presents a compelling argument on the limitations of human information processing, particularly intuitive judgment, in light of the current and future explosion of available information. Smith and Sage (1991) seem to adopt a more moderate and positive view of human intuitive capability with regard to situation assessment. However, both seem to agree that the role of decision *aids* will become prominent in the future. Smith and Sage provide form to this notion of decision aid in terms of an inquiry system. The value of human decision aids lies in the fact that they should not be believed, but used. Additionally, they permit the human to think "smarter" and more comprehensively by allowing certain intuitive operations that the user performs inadequately or inefficiently to be avoided.

In terms of an expert system, these decision aids or inquiry systems will expose or illuminate some of the hidden intuitive assumptions for extensive scrutiny and validation that were previously taken for granted. Paradoxically, this supports the enhancement of human intuition by equally exposing the fallibility's and limitations of the decision aids themselves. Finally, considering that the warrior will almost always be performing situation assessment based on continually pulled and updated fused information, he will invariably experience some sense of time compression. Therefore, the warrior may not have the time to consult or use a decision aid. However, it is Hogarth's contention that although human intuition may be inadequate to perform situation assessment in light of the information explosion and complexity of the battlespace environment, the fact that the warrior has been trained and familiar with the decision aid process will only serve to enhance his intuitive judgmental processes and improve his situation assessment as well as decision making. One such decision aid that is currently in research and development that

may demonstrate this intuition improvement phenomena is KOALAS and is the subject of the remainder of this thesis.

VI. KOALAS OVERVIEW

*We do ill to exalt the powers of the human mind,
when we should seek out its proper helps.*
— FRANCIS BACON

As indicated by Figure VI-1, this chapter will introduce and discuss one approach to facilitating information fusion and situation assessment known as KOALAS or the Knowledgeable Observation Analysis-Linked Advisory System.

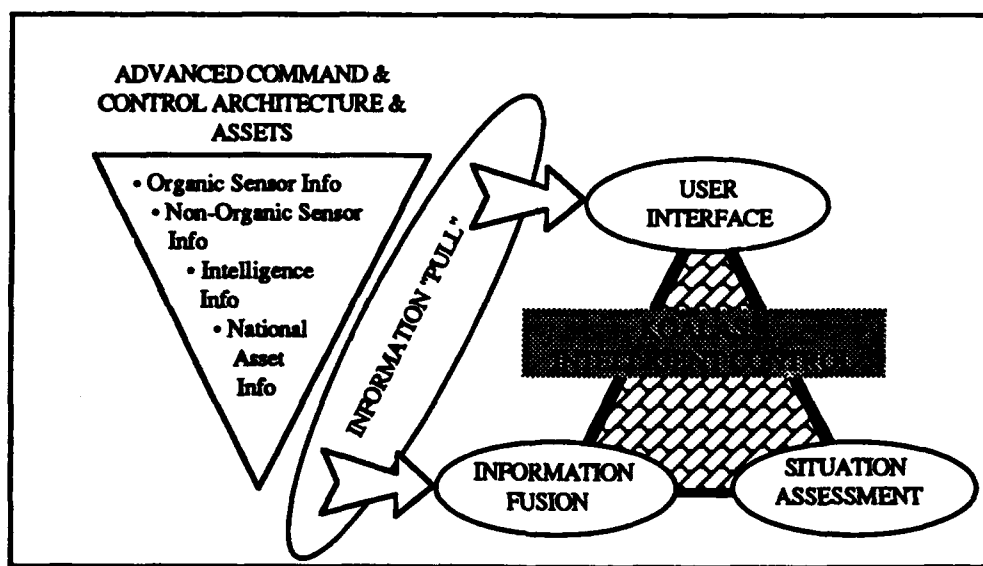


Figure VI-1: KOALAS and C4I

KOALAS is an outgrowth of several principal considerations. First, there is an unquestioned recognition that the environment that will confront the warrior of tomorrow will be increasingly dynamic, complex, and uncertain. Second, it is generally held that the warrior's performance will depend more greatly on his access to information that impacts and represents his battlespace (user information pull). Third, information is increasingly a

battlespace "commodity" and will be "traded" in terms of quantity and quality (information fusion). Finally, and most importantly, it will be the warrior's cognitive ability to interact, manipulate, process, and generally make sense of this information that will enable the warrior to achieve victory — by minimizing the effects of Clausewitz' "friction" and seeing through his "fog of war" (situation assessment). These four considerations are instrumental to implementing the advanced C⁴I architectures discussed in Chapter II. KOALAS represents a new "twist" within conventional command and control theory. Embedded in this twist is the notion of intelligent control and the idea that innate human intuitive abilities have been long overlooked and vastly underrated when it comes to designing C⁴I systems to expressly exploit this uniquely human phenomena and press home the advantage.

A. INTELLIGENT CONTROL

Barrett and Donnell introduced the concept of intelligent control in relation to real time expert systems (Barrett and Donnell, 1990, p. 15). In simple terms, the notion of intelligent control may be akin to the adage "work smarter, not harder." Barrett and Donnell make an observation that focuses the issue squarely onto human factors: "It is probable that the problems encountered in real time decision support, usually attributed to a technological limitation such as processor speed, arise instead at the foundations, at the structural-functional interface of the implementation concept to its function. (Barrett and Donnell, 1990, p. 15)" Intelligent control serves to illustrate this interface as the vital component in human interaction with any environment. As discussed in previous chapters, this interaction may be referred to as human-technology or human-information interface.

Intelligent control processes attempt to support and aid human cognitive performance by interlacing human inductive reasoning (intuition) with computer deductive reasoning at and within this interface. To accomplish this, intelligent control architectures rely on valid

situation assessment supported by information fusion schema. For further edification, Figure VI-2 represents the KOALAS taxonomy of intelligent control processes.

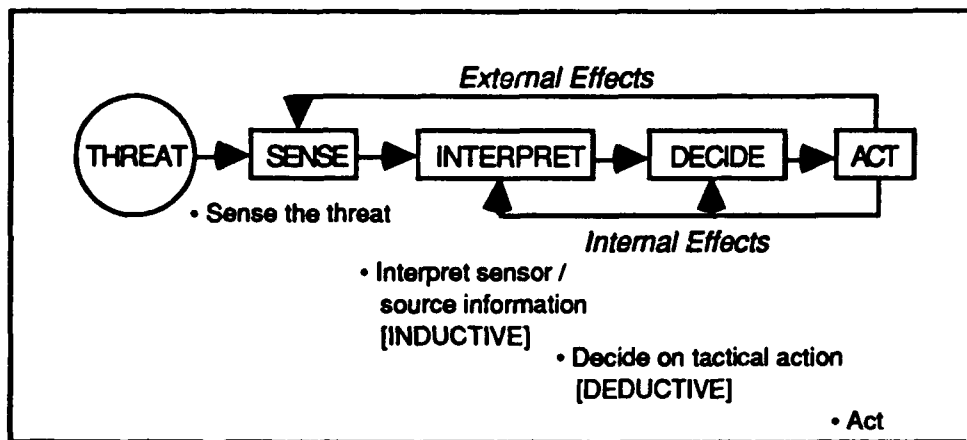
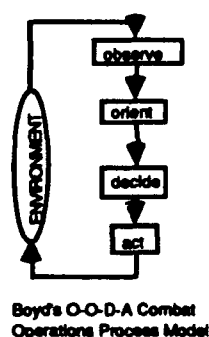
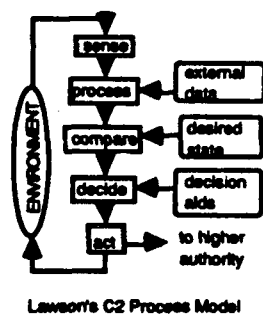


Figure VI-2: KOALAS Taxonomy of Intelligent Control Processes (after Harris, et al., 1991)¹

This figure indicates the separation of inductive and deductive processes (Harris, et al., 1991, p. 8). Regarding this taxonomy, Barrett and Donnell strive to make a key thematic point to the value and specificity of intelligent control:

In most real world human-machine decision systems, the final decision authority — an action assignment prerogative — is reserved for the human.... This can be as simple

¹This intelligent control process appears remarkably similar to Lawson's conventional C2 process models as well as Boyd's Combat Operations process model. (after Orr, 1983, pp. 42-43)



as an override or shutdown switch on a machine tool, or as complex as a military commander's judgment and authority over his or her forces. It is important to consider that such a common involvement of humans in system functions exists precisely where the present (Figure VI-2) functional taxonomy of decision process places the inductive processes and the burden of intention and interpretation. (Barrett and Donnell, 1990, p. 19)

The key role within the taxonomy is the interpretation process. This is essentially a one-to-one correlation to situation assessment as discussed in Chapter V and revisited above.

Harris, et al. (1991), provide an easy and simple explanation of intelligent control as a process and as a goal. Consider that a control system is comprised of three subsystems: sensors, a controller, and the controlled plant. The sensors are the points of contact between the reasoning system and the environment. In this case, the reasoning system will be a warrior's command and control. Based on events in the environment (battlespace), the sensors send a signal to the controller (warrior), which compares the signal with a desired setting. The controller then sends a signal to the controlled plant (military forces) to take specific action. The key to understanding here is that the warrior functions and operates not on or within the real world or battlespace, but rather on the sensor signals and a model that represents the real world. It is the nature of this model that determines the characteristics of the control system. Accordingly:

In the simplest control system, there is a one-for-one correspondence between observable parameters and the structure of the model.... When the model embodies parameters whose values cannot be directly registered by sensors, we say the controller operates on an over-parameterized model. When the controller reasons about sensor data or about the model to estimate the parameters that cannot be measured directly, we call the system an intelligent control system. (Harris, et al., 1991, p. 3)

Additionally, according to Harrison, Ratcliffe, Owens, and Harris (1991), an intelligent control system is comprised of sensors, sensor processing, interpretation, decisionmaking, and action assignment processes. This view is synonymous to the view presented in Figure VI-2, above. In essence, a control system uses a model of its environment and of the forces it controls. In conventional control systems, parameters of the model can be observed or computed from sensor observations. The military battlespace

is not that simple. The command and control system that interfaces with the battlespace cannot directly measure, observe, or compute all of the parameters associated with this battlespace. Thus, the warrior finds himself estimating, forming hypotheses, and reasoning about the battlespace and his forces. This reasoning is the foundation of intelligent control.

In terms of the command and control process, the battlespace is observed by sensors or other information sources. These sensed signals are then subject to interpretive process (fusion) to generate hypotheses about the battlespace within which the control system is operating (situation assessment). The decision process operates upon these hypotheses to formulate the objective course(s) of action. These courses of action are communicated to the warrior via the action assignment process in order to effect control. Finally, the action processes interact with the battlespace and the internal C² environment and the entire process repeats. In sum, the KOALAS idea of intelligent control may be viewed as an attempt to achieve a higher order, or metalevel, command and control by focusing on the human interpretive processes contained within the taxonomy. (Harrison, Harrison, Parisi, and Harris, 1992, pp. 1-2)

1. Fusion - A Conceptual Shift

As indicated above, intelligent control is grounded in the attempt to support valid and accurate situation assessment via sensor fusion. This notion can be expanded to cover the concept of information fusion presented in Chapter IV. It is appropriate to provide a brief review of conventional fusion schema to focus the discussion on the intelligent control difference. As Harris, et al. (1991), points out, "If there were perfect sensors, sensor fusion would not be necessary."² He advances the idea that the value or

²The reader's attention is directed to Chapter IV and the topics of information uncertainty, battlespace complexity, spectral diversity, etc.

quality of the information provided by conventional fusion schema is a "deductive consequence of the measured values in the sensor reports, not an induction from effects to cause." These fusion systems are at times referred to as data-driven because they are constructed around numerical correlation and/or logical association of sensor reports and database information. Contrastingly, Harris introduces the notion of hypothesis-driven fusion systems which are elaborations of the more simple data-driven schema. In this fusion schema, "A causal hypothesis (or multiple causal hypotheses) about the 'real world' and the state of the control system with respect to the world (the system state) is constructed of many symbolic objects in some specified functional relationship." Figure VI-3 illustrates these fusion schema. (Harris, et al., 1991, pp. 5-6)

The upper diagram represents the more conventional fusion system where the human operator is functionally separated from the fusion process. As shown in the figure, various sensors, such as radar, infrared search and track, television control set, and data link provide track files (labeled as Tr_x , Ti_x , etc.) to the multisensor integration (MSI)³, or fusion, component which in turn, provides its own tracks to the information display unit. The human operator (HO) observes the MSI system's track file display and *selects sensor modes* and trains sensors on *areas of interest*. The operator selects different sensor modes to improve the discrimination performance of a sensor against a threat that he believes to be indicated on his display. The selected sensor mode results in new sensor data that cause the sensor to alter its track file output, which in turn affects the MSI system output. This notion can be easily applied to a variety of information sources dependent upon the

³Recall the brief discussion in Chapter IV, Fusion, concerning the difference between sensor fusion and integration. The reader is invited to consult Luo and Kay (1988) for a more detailed synopsis. For purposes of this review, fusion and integration will be used interchangeably.

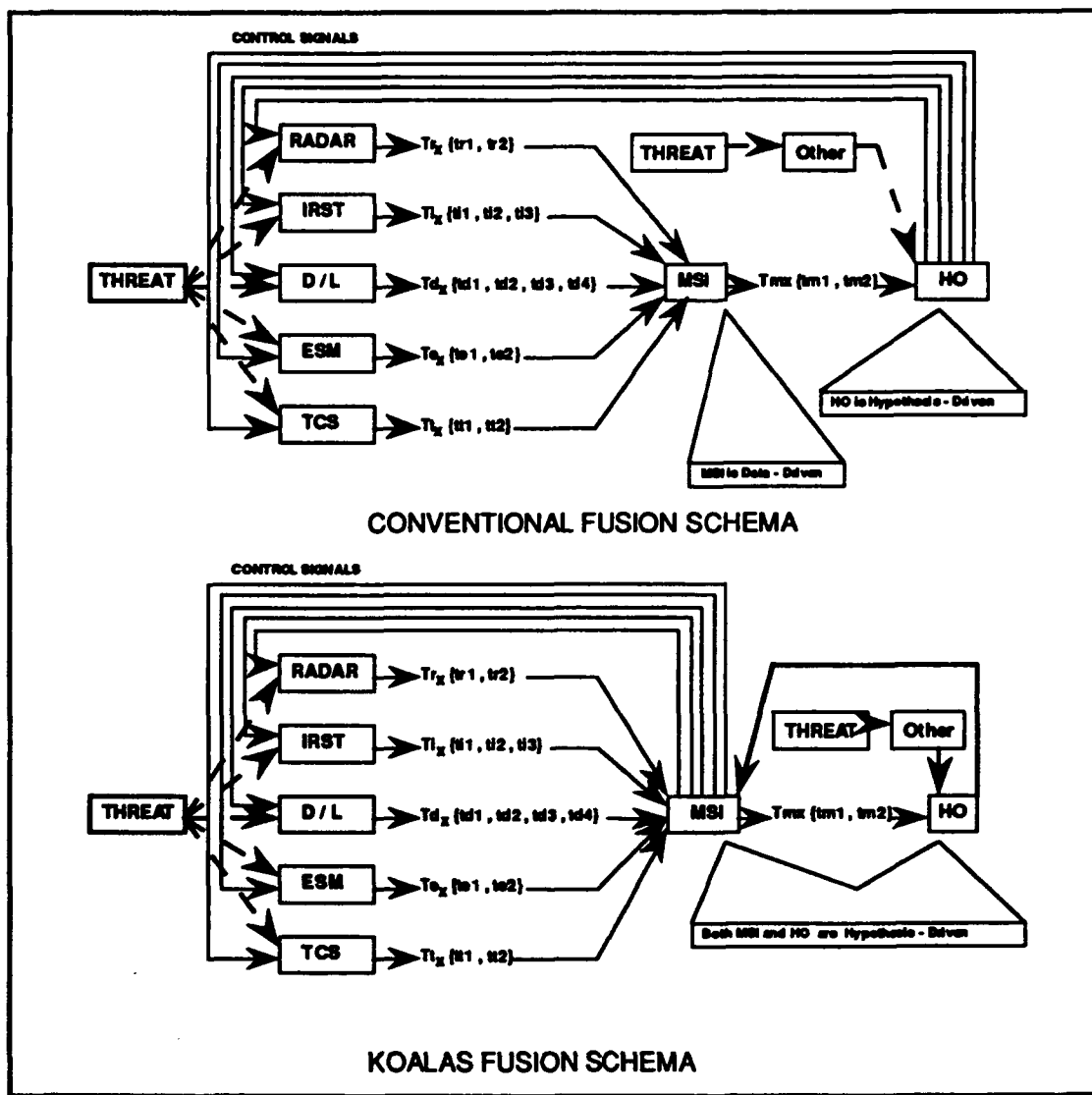


Figure VI-3: Fusion Schema Comparison (After Harris, et al., 1991)

representational metaphor. According to Harris, et al. (1991), this process may be referred to as manual MSI and is characterized as data-driven. (Harris, et al., 1991, pp. 8-9)

Contrastingly, the lower diagram is a simplified intelligent control sensor fusion schema that introduces the human operator more explicitly and integrates his functionality. This hypothesis-driven system treats the human operator inputs as another source of information. The operator is less concerned with managing sensor operation

(note the reduced number of control lines he originates), and more focused on the fusion process. He manages this process by identifying areas of interest, search constraints, and high-interest tracks to name a few. In this schema, the warrior generates and controls the inputs into his sphere of situational awareness based on his formation of causal hypotheses.⁴ "The operator explicitly instantiates his cognitive model of the tactical situation into the MSI (fusion) system, by specifying objects, relations among objects, his own goals, and constraints on the problem." (Harris, et al., 1991, pp. 8-9) This is the kicker, so to speak. Human decision making is hypothesis-driven. There is a significant difference between assumptions underlying the conventional sensor fusion systems architecture and human decision making processes. Within this difference lies the opportunity to enhance not only the system performance but that of the human operator as well. In this case, the contrast is more than a difference, it makes the difference. (Harris, et al., 1991, pp. 9-10)

2. Situation Assessment - Making It Better

Intelligent control is not a panacea. It remains flawed because humans are flawed. Warriors make judgments based on a model of the battlespace generated by inaccurate sensors providing uncertain information.

In an operational combat system, the operative hypothesis (i.e., the hypotheses upon which the controlling authority directs that action is taken) is almost never exactly correct.... Determining the operative hypothesis upon which to act requires induction to a causal explanation based on incomplete and errorful evidence about effects. The causal explanation must encompass the enemy's intentions; an inherently unobservable parameter of the threat model.... Interpretation is simply not a deductive problem. (Harris, et al., 1991, p. 4)

The most important factor contained within the intelligent control process is fostered in the interpretive processes by which situation assessment is conducted. Therein

⁴Recall discussion in Chapter V, Situation Assessment, concerning the argument that intuitive predictions are based largely on an individual's causal understanding of the world.

lies a possible solution that serves to mitigate the errors resulting from a complex, dynamic, and uncertain battlespace.

Situation assessment and decisionmaking involve highly interdependent interpretive process. These interdependent interpretive processes comprise both deductive and inductive components. Deduction is the forte of computers, so deductive components in interpretive processes are good candidates for automation.... Automatic induction is more problematic.... Induction is something humans do quite well. Induction is a function of the human decisionmaker's current combat experience and objectives, the geopolitical consequences of error, one's expectations of the enemy's motivation and intent, and myriad other factors that are also not yet computable. (Harris, et al., 1991, p. 4)

Several key points are made here. First, the explicit statement that the warrior's situational assessment is an interplay of both deductive and inductive logic processes. This interdisciplinary phenomena takes the ideas presented in Chapter V, Situation Assessment, one step further.⁵ The intelligent control process attempts to forge a discreet, identifiable, and qualitative link between computer-based decision support (deduction) and the powerful insights generated by human intuition. Second, the integration of deductive and inductive logic will occur as an outgrowth of the technologies discussed in Chapter III. Finally, this integration will be achieved at the interface between the warrior and the battlespace. This interface is where information fusion meets situation assessment.

B. KOALAS ARCHITECTURE

KOALAS was designed around the notion of intelligent control. As described, intelligent control incorporates human induction and hypothesis-driven fusion schema to support situation assessment. The warrior operates within the KOALAS taxonomy by controlling the operative situation hypothesis and the actions prescribed by the system. Conceptually, then, an architecture is constructed by which this taxonomy is framed. "The

⁵Essentially, that situation assessment is an information processing phenomena resident within *separate* human deductive and inductive reasoning components and not *jointly* as presented here.

KOALAS architecture provides support for human induction, it incorporates an explicit model of the human operator's tactical situation assessment, and it provides a context for the appropriate use of sensor fusion systems in the initialization and maintenance of that situation assessment." (Harris, et al., 1991, p. 7) Figure VI-4 provides an illustration of the KOALAS architecture. As depicted in this figure, the components include a Sensor Data Manager, an Induction Control Interface, an Evidence Manager (a rule-based expert system), a Deductive Decision Engine (knowledge base), a Database (object attribute database), and a Hypothetical World Simulation. A brief overview of operation is drawn from Harris (1991) and provided here:

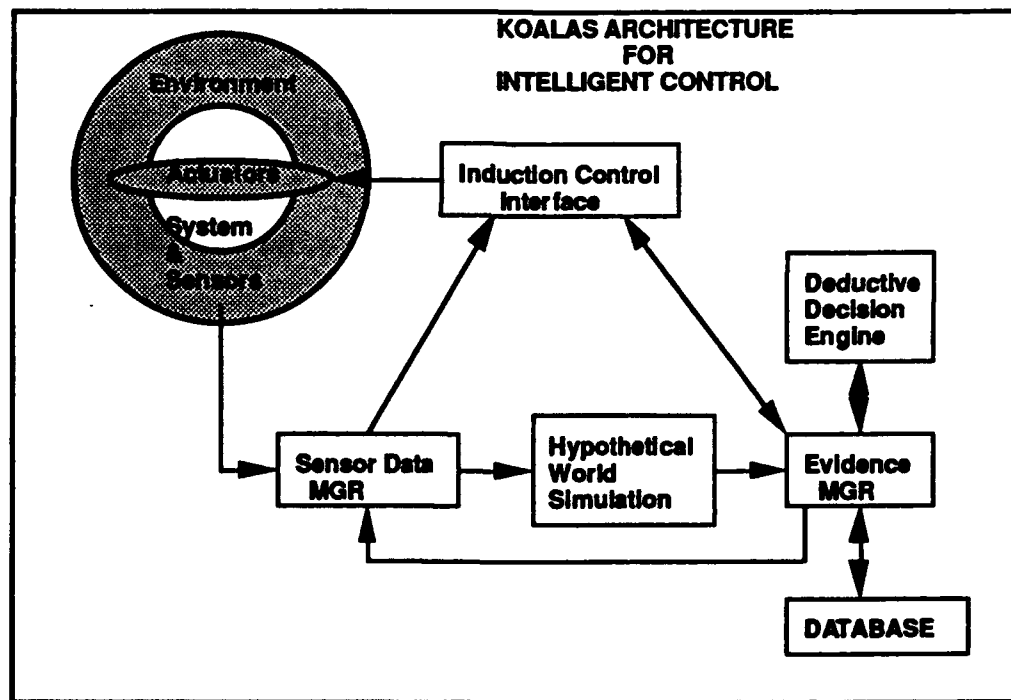


Figure VI-4: KOALAS Architecture (after Harris, et al., 1991)

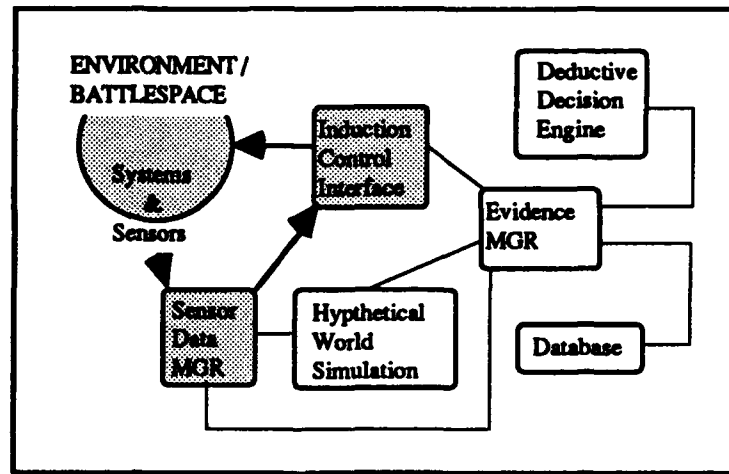
... the operative situation hypothesis is arrived at by induction, performed by the human operator on the basis of: (1) raw sensor data; (2) fused sensor data that represents deductions performed by the sensor fusion subsystem; and (3) other information resources not available to the system (e.g., by verbal communications channels). The

operator explicitly instantiates his hypotheses, i.e., his cognitive model, about the problem into the system through the Induction Control Interface. Through the Induction Control Interface the operator inserts, alters, and deletes objects in the Hypothetical World Simulation component. (Harris, et al., 1991, p. 10)

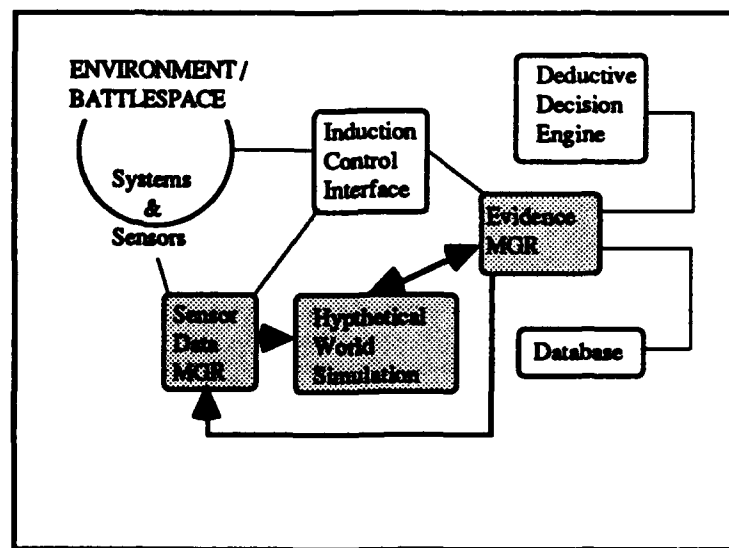
Before continuing with a description of specific components, two observations may be made. First, the "fused sensor data" referred to above would be derived from fusion schema introduced and discussed in Chapter IV. The process of fusion is not so much an issue at this point as is the control and monitoring of the process. This is where KOALAS makes a real impact. Second, the "other information resources", also mentioned above, are an anachronism relative to the advanced C⁴I architecture initiatives discussed in Chapters II and III. These architectures provide the bandwidth, access, and processing power necessary to disavow "sensor data" and "other information resources." Rather, the inputs to this KOALAS intelligent control architecture will only be in terms of classes of information, all of which will be available. This represents not only a change in semantics, but a shift in the very foundation of conducting C2.

The following conceptual expansion of the intelligent control processes represented within the KOALAS architecture is synthesized from Harrison, et al. (1991), Harrison, et al. (1991), and Harris, et al. (1991) and presented in a step-by-step functional analysis.

- Sensor data is sampled by the Sensor Data Manager in a directed search for confirming/discrediting information as directed by either the Hypothetical World Simulation or the warrior.



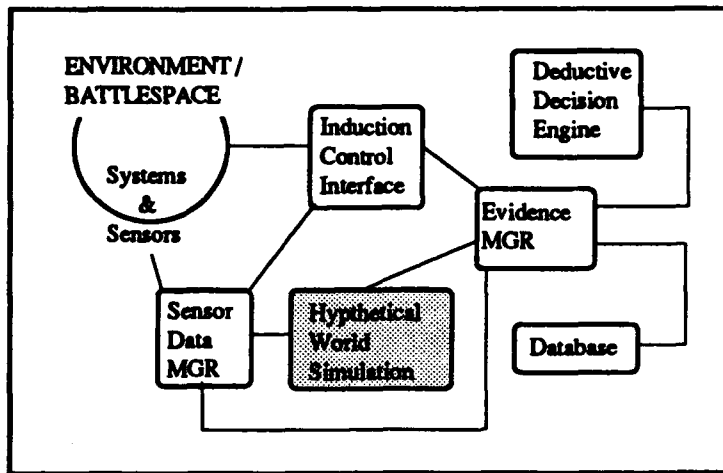
- An evidence function is computed by an algorithm that estimates the difference between new sensor/source information and the previously computed world state model⁶ being updated/maintained by the Hypothetical World Simulation.



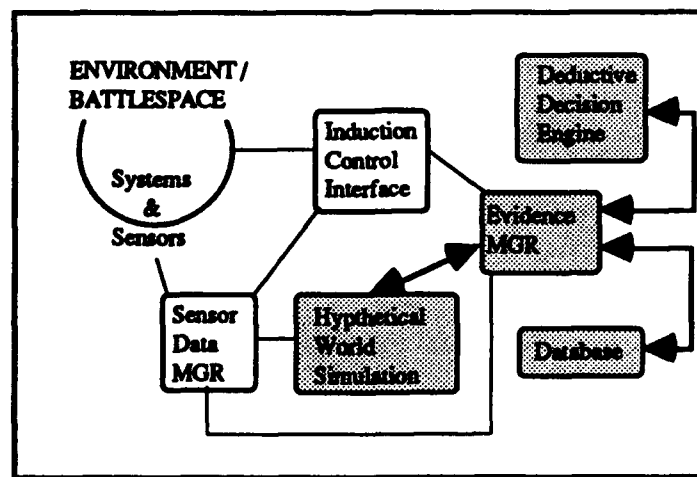
- The Hypothetical World Simulation is implemented in an embedded object oriented simulation — essentially a software wargame using battlespace sensor/source

⁶Recall the discussion in Chapter IV and Figure IV-5 concerning the generation, maintenance and use of a world model by which to aid situation assessment. The world model may be viewed as a simulation of the battlespace within which the warrior can "game out" the result of sensor tasking, force orders, enemy movements, etc.

information as inputs. This "wargame" includes explicit representation of temporal and spatial characteristics of the simulated battlespace.⁷



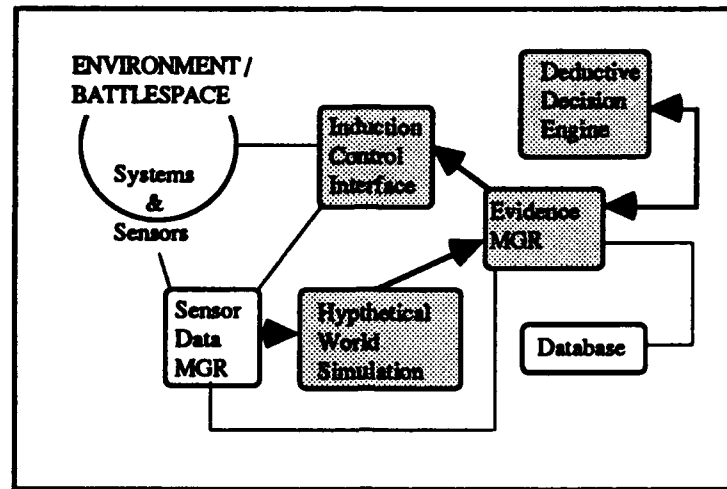
- The Evidence Manager receives the current situation hypothesis and predicts future values for sensor data based on stored information contained in the database and deduced information derived from models of the objects in the situation hypothesis. The Evidence Manager makes updated hypotheses about the battlespace to the Deductive Decision Engine. This is an expert system that provides advice on action to be taken. The Hypothetical World Simulation is updated continuously.



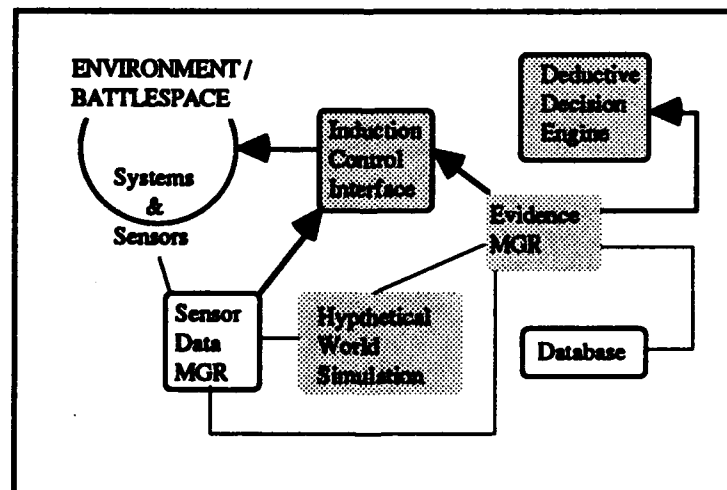
- The Hypothetical World Simulation synchronizes sensor data, and then makes an updated hypothesis about the battlespace to the Deductive Decision Engine via the

⁷Recall the issues of spectral diversity in Chapter IV, Fusion. The model presents to the warrior, in a transparent fashion, the fused information which resolves the geographic, temporal, and measures of effectiveness uncertainty associated with any system of sensors or information sources.

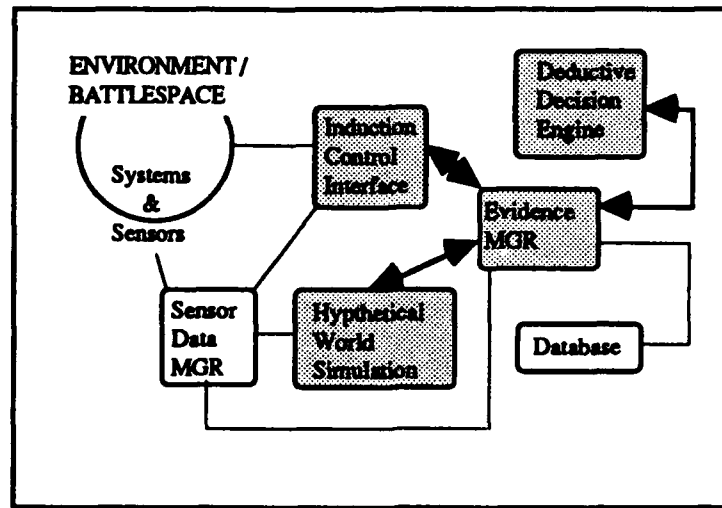
Evidence Manager. The Deductive Decision Engine advises the induction process on action to be taken.



- The key feature in the KOALAS approach is the Induction Control Interface. This is the open loop control point in the architecture. The warrior interacts with the C² system through the Induction Control Interface. The Induction Control Interface presents raw sensor/source information and system hypotheses to the warrior, displays the results of the hypothesis support function, and provides the user-information or user-technology interface for:
 - (1) viewing situation hypotheses;
 - (2) modifying the situation hypotheses;
 - (3) designating the operative hypothesis;
 - (4) querying the Deductive Decision Engine for explanations; and
 - (5) viewing raw/fused information as the warrior pulls it.



- The warrior controls the variance between the situation model in the Hypothetical World Simulation and his own cognitive model. Ideally, the hypothesis/course-of-action combination(s) generated by the warrior and the Evidence Manager/Deductive Decision Engine expert system will corroborate and validate each other.



In summary, deduction is carried out by the expert system component. Induction, which cannot be automated, is controlled by the warrior. KOALAS links the two. This implicit system orientation on the warrior has the potential to amplify his intuitive understanding. (Harrison, Ratcliffe, Owens, and Harris, 1991, pp. 1-3 & Harris, et al., 1991, pp. 10-11 & Harrison, Harrison, Parisi, and Harris, 1991, pp. 2-3)

C. WHAT IT ALL MEANS ...

KOALAS is not a command and control architecture. It is a methodology that can amplify the benefits of C² and minimize the detractors associated with the "fog of war." As Harris, et al. (1991), state, "The ... power of the KOALAS approach [is] in overcoming some critical shortcomings of conventional sensor fusion methods for situation assessment applications, by explicating the relationship between sensor fusion and situation assessment from the perspective of the intelligent control concept." (Harris, et al., 1991, p. 3)

KOALAS and its foundation of intelligent control is an effort to fully exploit information

fusion⁸ in support of situation assessment by establishing a synergistic link between computer aided deduction and human induction and intuition.

The components described above are not only viable, but they exist. Additionally, the technologies advanced in Chapter III⁹ will only serve to refine the fidelity and increase the robustness of future intelligent control systems. These technologies will increase the accuracy, precision, and completeness of existing and future fusion systems while simultaneously reducing the uncertainty associated with the battlespace.

Similarly, the human cognitive limits addressed in Chapter V can be minimized by separating the deductive and inductive reasoning components. This separation enables the warrior to focus his energies on "making sense" of the battlespace. Perhaps more importantly, the warrior gains tactical advantage by operating within the enemy's C² process by discerning, anticipating, and understanding that nebulous variable of intent.

In summary, KOALAS represents a viable methodology with which the warrior can fully realize the performance gains that the advanced C⁴I architectures proposed in Chapter II promise. As stated previously, one fundamental design point of these advanced C⁴I architectures is the ability of the warrior to pull the information he feels is necessary for him to best prosecute his mission within his battlespace. KOALAS promises to deliver this information in the context¹⁰ he wants it, where he wants it, and when he wants it. The open loop control feature of the Induction Control Interface enables the warrior to instantiate his perceptions, understandings, and hypotheses within the intelligent control

⁸The notion of intelligent control discovered in research pertained almost exclusively with the more limited concept of sensor fusion. That is, the great body of research seems to be focused on controlling and managing the product of conventional sensor devices (radar, ESM, IR, etc.). This thesis explores the viability of viewing this fusion process in terms of information from a variety and multitude of *sources* as a whole vice simply *sensors* in the narrow form.

⁹For example, databases, synthetic environments, virtual reality, intelligent agents, hypertext, artificial intelligence, expert systems, neural networks, fuzzy logic, genetic algorithms, et al.

¹⁰Recall the discussion of *form* and *format* contained in Chapter II, Advanced Architecture Initiatives.

system by *controlling* in lieu of *conducting* the C² process. The user-technology interface represented by KOALAS may then begin to anticipate not only the state of the battlespace, but the information needs necessary to fully evaluate the environment. It may well be this information "anticipatory" feature which enables and focuses the warrior's intuition.

VII. KOALAS RECOMMENDATIONS

The perfect is the enemy of the good.
— VOLTAIRE

As indicated by Figure VII-1, below, this chapter will discuss a broad integration of KOALAS within the advanced C⁴I architectures relative to human factors and some resulting derived benefits.

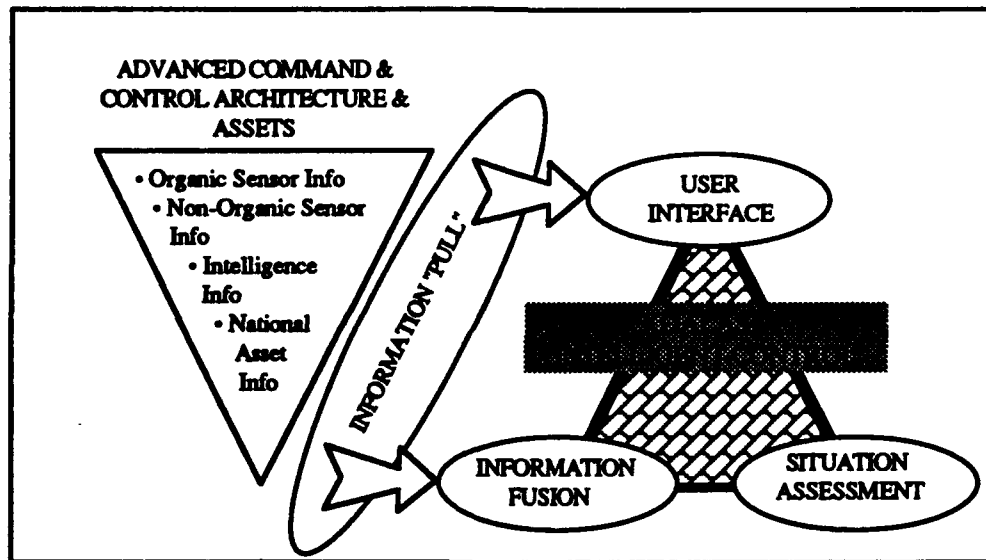


Figure VII-1: KOALAS and C⁴I

The intelligent control process contained within the KOALAS system and discussed in Chapter VI is by no means the "panacea" to the implementation of advanced C⁴I architectures. At this point it may be prudent to refamiliarize the reader with the concepts contained within C⁴I and the preceding chapters of this thesis. C⁴I is, of course, command, control, communications, computers, and intelligence. Evolutionary terminology holds that the next variant will be C⁴I² with an "information" attached at the

end of the list. However, current shifts in the world geopolitical situation mandate a change in the roles and missions the military will be expected to execute. In response to this dynamic environment, new command and control architectures are being proposed and implemented. These were discussed in some detail in Chapter II, Advanced Architecture Initiatives, and focused principally on the role of the warrior and the fact that he is now the center of the structure and no longer on the periphery. Chapter III, Information Pull and Technology, developed the idea of information pull. It is just this concept that establishes the pre-eminence of the warrior within these advanced command and control frameworks. Chapter IV, Fusion, discussed the idea of information fusion and established the necessity for these systems and the advantages they provide. Chapter V, Situation Assessment, developed the notion of situation assessment, particularly in terms of human cognitive limits and intuitive perceptions. These five chapters established the idea that the advanced command and control architectures were a good idea but could be better. Chapter VI introduced KOALAS, an existing initiative that links human cognitive processes, particularly intuition and inductive reasoning, to fusion and situation assessment, thereby maximizing the warrior's performance.

A. ADVANCED C⁴I ARCHITECTURE - KOALAS INTEGRATION

The first step in command and control is executed when available information is evaluated and assessed to gain an understanding of what is happening within the battlespace. This information is derived from sensor and source data and intelligence that is communicated to the warrior and processed (stored, handled, manipulated) by computers. Sensor and source data is unintelligible by itself. It is only when the warrior places the data into his reality or situation assessment that it becomes information and knowledge. In short, information is a natural product of the C⁴I architecture. Interfacing with this architecture, then, becomes the key to tactical success. KOALAS provides a possible

solution, but is by no means complete. Presented below in Figure VII-2 is an integration of KOALAS [Figure VI-4] with the conventional fusion concept [Figure IV-6] that may further enhance the warrior's cognitive performance.

In viewing Figure VII-2, several modifications are readily apparent. First, the conventional sensor systems represented in Figure IV-6 have been replaced with the broader sensors and sources of organic, non-organic, national, and intelligence information. Commensurably, the sensor tracking functions of Figure IV-6 have been replaced with a "network" function representing the virtual connectivity and information pull execution contained within the advanced C⁴I architectures. Second, the Situation Database has been replaced with the KOALAS Situation Database. This database supports the model simulation, situation assessment, and information fusion. Third, the conventional Data Combination and Reasoning has been replaced with the KOALAS Deductive Decision Engine. Fourth, the conventional Situation Assessment and Alternative Analysis function has been detailed to include the specific KOALAS components of the Hypothetical World Simulation and Evidence Manager. Finally, the conventional Command and Control block has been modified to include the KOALAS Induction Control Interface.

This integration is conceptually complete and functionally precise. KOALAS intelligent control provides a complete linkage between the information fusion and decision support subfunctions contained within current C⁴I architectures. Historically, these processes have been completed as an abstraction of a warrior's warfighting abilities. Fusion and situation assessment were approached in a serial fashion procedurally and conducted in a rigid lockstep doctrinally — further analysis, fusion, or assessment could

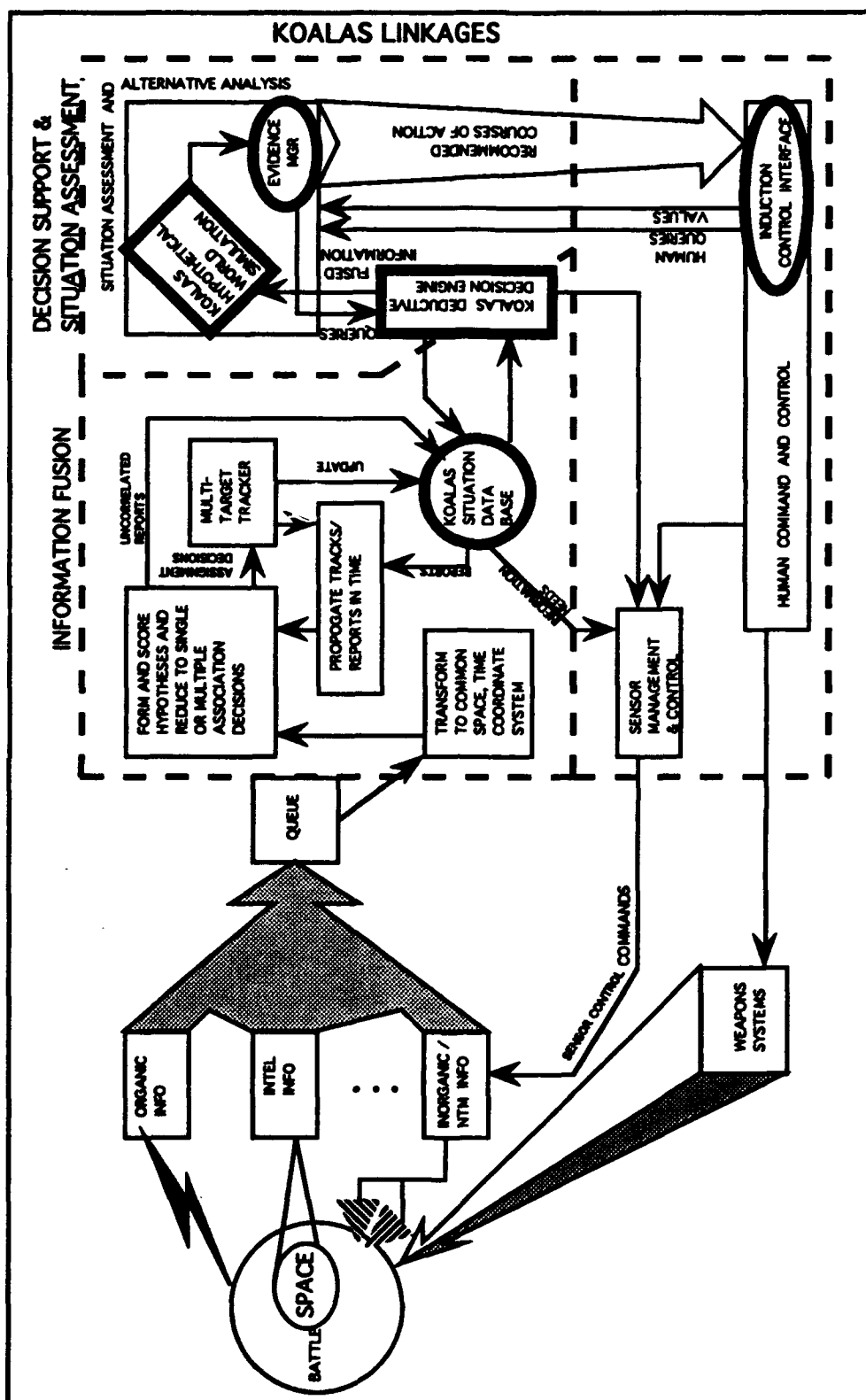


Figure VII-2: KOALAS and Conventional C2-Fusion-Situation Assessment Integration

not be performed without receiving new information, guidance, or tasking. KOALAS explicitly separates these functions from the labyrinth of chaos and confusion found within conventional C² architectures, systems, and organizations. This linkage enables information fusion and situation assessment to be performed in a continually updated, iterative fashion by accepting the perceptions of the warrior.

More importantly, KOALAS provides the opportunity to establish truly effective user-information and technology interfaces in a modular fashion. The architecture readily supports this concept via the Induction Control Interface. This element will be the warrior "plug-in" point. This is where his personalized C⁴I is created and maintained. This is where user information pull becomes a reality. Seamless and transparent operations will be achieved at the Induction Control Interface through the proper design and incorporation of human engineering principles. Common operating environments and real time decision aiding will be the functional architecture upon which the Induction Control Interface is built.

B. POSSIBLE IMPROVEMENTS

However, while KOALAS is a promising reality in meeting the goals and providing the deliverables that the advanced C⁴I architectures promise, it can be improved. This improvement should be focused at the Induction Control Interface. At this point, it is prudent to revisit some of the issues discussed in previous chapters. Specifically, the idea of open loop control¹ and an inquiry system.² KOALAS promises to allow the power of

¹Open loop control was introduced in the KOALAS overview, particularly relative to the Induction Control Interface. The induction control interface is where the warrior interacts with the C² system and is the "open loop" point in the KOALAS approach.

²The idea of an Inquiry System was introduced in Chapter V, Situation Assessment. An inquiry system is a vehicle which allows the warrior to monitor and perform situation assessment and enables him to achieve a higher degree of fidelity and control over this process.

human intuition into the situation assessment loop. Additional thought ought to be given to amplifying this power.

1. Open Loop Control

KOALAS implicitly prescribes an open loop control methodology which enhances the warrior's ability to fuse information in support of sound and accurate situation assessment. The explicit incorporation of an open loop control schema within the KOALAS framework is one alternative to improving the integration of KOALAS within the advanced C⁴I architectures. The idea of open loop control is best explained relative to the more easily recognizable closed loop control. Closed loop control may be thought of as taking action based on results and open loop control as taking action based on anticipated events. In order to act anticipatively,

"...the executive process [C²] must increase its issue scanning and tracking activity ... there must be increased organizational learning if the organization is not to become chaotic. The benefit of open loop control is that the organization is able to have faster decision making and respond to changes in its external environment faster." (Widmeyer, 1992, p. 166)

The concept of issue scanning and tracking correspond directly to the sensor/source information fusion and situation assessment. The ability to have faster decisions and respond to external change quicker is easily transferable to the warrior's desire to execute C² effectively. Widmeyer (1992) continues, "There is a strong link between having knowledge (information fusion and situation assessment) and the capability for a swift and apt response (C²) from the organization [warrior] with respect to events in the external environment (battlespace)." (Widmeyer, 1992, p. 170)

2. Inquiry System and Learning

The concept of organizational and individual learning is embedded within the idea of an inquiry system. An inquiry system is used to aid the decision maker in defining

and solving a problem and represent a second alternative to integrating KOALAS within the advanced C⁴I architectures. Sage presents the following goals of an inquiry system:

... inquiry systems need to be able to determine whether what the decision maker perceives as information is actually information An inquiry system should be capable of recognizing the goals of the decision maker, determining what information is relevant to the task at hand and what is not, and summarizing this information in a form that is suitable for the decision maker and in the sense of being compatible with various contingency-related elements of the task, such as time available for judgment and choice. (Sage, 1991, p. 246)

The design, creation, and implementation of such a system will be achieved through advanced technologies. However, it is within the fundamental precept that humans apply intuitive strategies to gather and process information that the value of an inquiry system becomes apparent. The Induction Control Interface may be viewed as a conceptually advanced inquiry system. Is not to displace the warrior, but rather to enhance and amplify his natural intuition that the idea of an inquiry system becomes reality.

3. Interface Control

The power of advanced C⁴I architectures and intelligent control can only benefit the warrior if the system is accessible and the product is intelligible. For example, one has only to look at computer technology and the revolution in user interface brought about by the Macintosh[®] operating system. Arguably, its success in the marketplace is derived initially from the appeal of its easy-to-use nature as opposed to its functionality, and processing or computing power. Similarly, this economic force precipitated competitors, like Microsoft, to cater to public demand by introducing the Windows[®] operating system. Both of these systems incorporate well designed screens, functional software tools, and ergonomic hardware to increase *human* processing speed, reduce *human* errors, and enhance *human* decision making productivity. One particular aspect of this relationship deals with what information is displayed, how information is structured, and where information is located. Advanced C⁴I architectures promise to delegate this

issue to the lowest possible level — or more appropriately, the new center of the system — the warrior and his interface. This functional requirement should be accomplished and contained within the Induction Control Interface.

One such interface controller is described by Yazici, et al. (1992). Figure VII-3 illustrates this control architecture as adapted within the KOALAS framework.

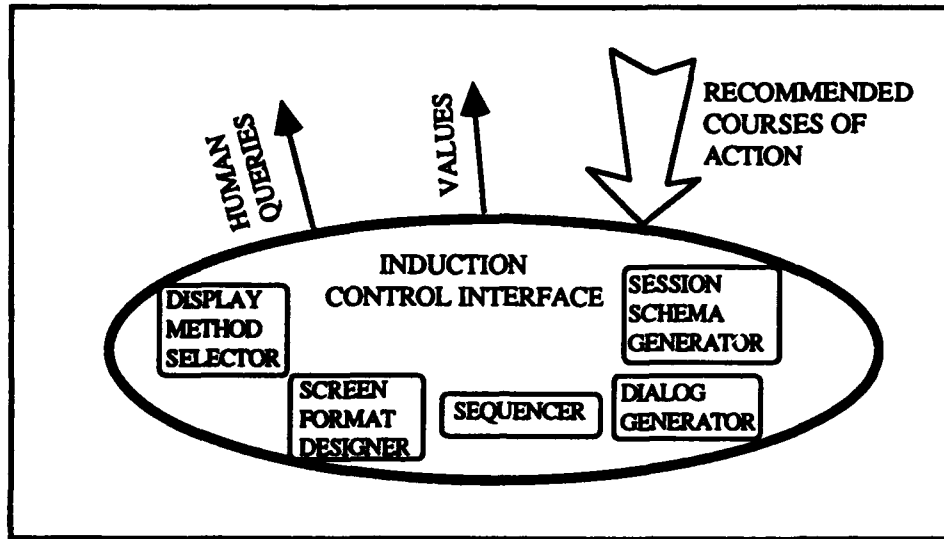


Figure VII-3: Interface Controller (after Yazici, et al. 1992)

As envisioned by Yazici, et al. (1992), the interface controller manages the interactions between the modules indicated in Figure VII-2. The operations of the modules are interactive and recursive³. Ideally, the controller is transparent to the warrior. The modules within the controller contain a learning algorithm where preferences are preset by the warrior and adapted as learning takes place. The following list summarizes the objectives of each component:

³In this sense, recursive means that the controller can "learn" from the warrior and apply this knowledge to other current and future functions.

- The Session Schema Generator monitors all the input and output functions as well as creates the plan of each user session. A session is taken to mean a series of interactions. Additionally, there would exist a connection between, for example, continuity of thought, memory, and expansion of previous ideas.
- The Dialog Generator is responsible for creating preplanned and impromptu dialogs during a session. Dialog would be based on natural language understanding, information syntax, and situation assessment context.
- The Sequencer monitors and develops the continuity of the session. This will be based on the user's cognitive characteristics, similar to his personalized C⁴I. This allows the user to navigate within the battlespace hypothetical model in a flexible manner.
- The Display Method Selector and Screen Format Designer determine and control how information is communicated to the warrior. This is the area that possesses the greatest potential for change by incorporating new media technologies like virtual reality, synthetic environments, and cyberspace. Currently, the display options will use conventional graphical user interface technologies, e.g., hypertext. (Yazici, et al, 1992, pp. 106-107)

The ideas presented above represent a broad conceptual view of some specific areas which, when considered in conjunction with the architecture as a whole, serve to focus attention on the need to truly consider the warrior in the design of his tools. The warrior needs to be able to easily understand his system and its capabilities and limitations. He needs to be able to control what he wants to see and the manner in which he sees it. Open loop control methodology represents one possible solution to aiding this task. Additionally, the warrior needs to be able to focus his intuition on the battlespace by viewing only what information is important. The development and integration of an inquiry system within the Induction Control Interface may accomplish this. More importantly, he needs to be able to interact with his battlespace intelligently by reducing the disorientation associated with useless information. The interface controller concept should assist this endeavor. These ideas represent the whole of the KOALAS concept - enable the warrior to fight more effectively by taking advantage of his intuition in order to match his efforts against what he wants to accomplish.

C. PERFORMANCE GAINS

The benefits derived from the implementation of advanced C⁴I architectures have been discussed in preceding chapters. Essentially, provide the information [fusion] the warrior wants in order to view the battlespace with clarity [situation assessment] so he can direct his forces to accomplish their mission [command and control]. KOALAS attempts to amplify or enhance this process. Harris, et al. (1991), provide a expected benefits or performance gains derived from experimental results.⁴ A synopsis follows.

First, there is an increase in weapon system lethal range. By employing sensors and sources within a KOALAS framework, the value of derived information enables the warrior to focus his weapons on "real" targets at maximum weapons performance envelopes. Erroneous, spurious, and dubious targets are easily recognized and discarded in favor of the true enemy. His command and control cycle time is reduced and his attention is more focused on the tasks at hand.

Second, the warrior will be less vulnerable to any deception operations being conducted by the enemy. The deductive expert system component of the system will provide margins of ground truth within the battlespace which permits the warrior to take advantage of his intuition based on his knowledge, experience, and operational expertise to increase the fidelity of his battlespace model or situational awareness.

Third, a broad application of KOALAS systems within and across multiple levels of the warrior infrastructure enables a synergistic amplification of hypothesis confirmation via information corroboration or disaccreditation. In essence, warriors on all levels can direct

⁴These performance gains are in-line with those goals and advantages presented in Chapters II and IV. For more precise information, the reader is directed to Harris, et al. (1991)

their forces based on accurate information and similar situation assessments resulting in the same operative situation hypothesis.

Fourth, KOALAS permits the injection and integration of unidentified technology within the architecture framework. This is particularly important considering the rapidity with which new information, weapons, and sensor technologies are being developed.

Fifth, KOALAS *enables* the warrior. Before, the warrior only used the tools, information and weapons, provided by his command and control hierarchy. Under this architecture, the warrior becomes the weapon via the KOALAS interface. Finally, KOALAS fosters intelligent thinking by the warrior. Where a warrior used to think as a function of his intelligence, he will now intelligently think. Previously, command and control was a function of organization. Command and control will now be approached in terms of a process - a process that enables the warrior to imagine.

D. ONLY A BEGINNING

KOALAS and the advanced C4I architectures reviewed are in their infancy. More mainline human engineering principles ought to be considered in the design and implementation of any C4I architecture to fully realize performance potentials. Nominally, the Inductive Control Interface, as represented by KOALAS, will display whatever "information" the warrior desires. The term "information" is used here because, conceptually, the incorporation of open loop control, an inquiry system, and an interface controller within a KOALAS Inductive Control Interface will serve to place sensor/source data into the warrior's cognitive reference. Currently, much research is underway in advanced presentational mediums for "getting the message across." As mentioned in Chapter III, these range from advanced graphical user interfaces to virtual reality to synthetic environments to cyberspace. However, like many concepts, they are encumbered not by technological limits, but by lack of inductive thinking on visualizing the technology

application or optimizing its utility. The beauty of intelligent control processes and a system like KOALAS lies in their inherent simplicity of form and elegance of function ... they can be applied to any system or organization, at any level, across any boundary, and between any echelon.

VIII. SUMMARY AND CONCLUSIONS

There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things, because the innovator has for enemies all those who have done well under the old conditions, and lukewarm defenders in those who may do well under the new.

— MACHIAVELLI

A. LOST HORIZONS

A common theme throughout this thesis is the idea of "change." As a result of changes in the economic and geopolitical structure of the world, the United States military will undergo a period of great transition. This change will become a constant force with which to be reckoned. Change is persistent. Change is immutable. The pace of change is increasing rapidly. The warrior's battlespace can be summed up in this one word — change. Consequently, the information that the warrior looks to in order to make war fighting decisions will be dynamic and uncertain. Combined with the adversity associated with the battlespace, the warrior is in danger of becoming subsumed in chaos. As discussed in Chapter II, current C⁴I architectures and processes are ill equipped to meet this change.

The advanced C⁴I architectures discussed, namely the Navy's Copernicus and the Joint Chief's of Staff C⁴I For the Warrior, are an effort to meet this change head-on. Current architectures are task, structure, organization and/or job oriented vice focused on the process. They are built upon stovepiped systems and organizations focused inward on the service component vice outward toward warrior. They are characterized by agency paralysis, inflexibility, and unresponsiveness. They generate activity, not performance. They follow procedures, not achieve goals. They were designed in the last century for a military force that needs to operate in the next century. Conversely, these advanced

architectures strive to ensure a military flexible enough to adjust quickly to changing battlespace environments, innovative enough to take advantage of new technology, and nimble enough to out-think, out-gun, and out-maneuver the enemy. In short, change the very nature of command and control. As discussed in Chapter III, the new command and control process will revolve around the warrior and an information "pull" vice "push" doctrine.

New technology will be the force that enables this information pull phenomenon. Information technology will allow the military to work in radical, previously undefined ways. Innovation that is incumbent on this technology will change the very process of how the warrior interacts with his battlespace and supporting organizations. The key feature in this interaction is the user-technology interface. It is at this interface that information pull will expand the limits of the possible. The impossible will become commonplace. The impossible will be achieved through enhanced information fusion and situation assessment as presented in Chapters IV and V.

Information fusion is taken to be an outgrowth of sensor and multi-sensor fusion algorithms. Situation assessment is taken to be an inherently human, or warrior, process. Both are key to the decisionmaking, and command and control process that a commander must undertake in order to succeed on the battlefield. Generally speaking, fusion is a function undertaken at the sensor, information source, or controlling agency level. Fusion is often conducted by computers based on remote systems characterized by spectral diversity — separated in time, space, and measures of effectiveness. Additionally, fusion is an attempt to reduce or minimize the error, ambiguity, and uncertainty associated with the resultant information. Conversely, situation assessment is a uniquely human process. Where fusion may be aided or even overtaken by machines, human cognition may only be emulated, but never replaced. However, human situation assessment may be assisted in

the manner and method of information manipulation. This manipulation is subject to the vagaries of "human factors." By extension, computer decision or command and control aid is achieved at the interface between the warrior and his information as discussed in Chapters VI and VII.

At this point, we have recognized the phenomenon of change - both as a problem and a solution. We have experienced the "old" and seen glimpses of the "new" in terms of command and control and representative architectures. We have reviewed the doctrinal shift toward the warrior as opposed to around the warrior in terms of information pull. Finally, we arrive at the warrior as the foundation of these advanced C⁴I architectures because they rely on his innate ability to take fused information and synthesize a complete and representative picture of the battlespace in which he must operate. Current command and control procedures are based on assumptions about people, organizational goals, and technology which are no longer valid. KOALAS and similar methodologies capitalize on technological innovation to reengineer the process by which the warrior conducts command and control.

KOALAS achieves a separation of human deductive and inductive reasoning processes with potentially breathtaking improvements in performance. This separation serves to isolate and minimize resultant human cognitive limitations by introducing expert system's deductive reasoning technology into the situation assessment process. More importantly, KOALAS enhances the warrior's natural intuition by first creating an environment that fosters its application and then combining it with computer decision aids. The yield is synergistic performance gains. This is not a new goal; it has just never before been realizable. In a battlespace that is at best uncertain, and at worst unknown, it will be the commander's intuition upon which success or failure will hinge. According to Clausewitz:

... the general unreliability of all information presents a special problem in war: all action takes place, so to speak, in a kind of twilight, which, like fog or moonlight, often tends to make things grotesque and larger than they really are.

Whatever is hidden from full view in this feeble light has to be guessed at by talent or simply left to chance. So once again, for lack of objective knowledge, one has to trust to talent or to luck.... the talent of the military genius, whose experience, intuition and character, equip him to make prudent decisions even in an environment of rampant uncertainty. [Handel, 1990, pp. 13-14]

It is impossible to change or accommodate the warrior's experience or character, but KOALAS indeed makes a positive impact on the warrior's intuition. By incorporating an "intelligent control" framework, KOALAS aids a warrior's intuitive capacity by impacting and changing the command and control process from the ground up. KOALAS exploits the latest capabilities of technology to achieve entirely new goals. KOALAS is predicated on realizing imaginative and ingenious solutions to dynamic problems occurring in an uncertain battlespace by enabling, reinforcing, a warrior's intuitive power.

B. NEW HORIZONS

The application and utility of the KOALAS intelligent control methodology is both broad and deep. As discussed, KOALAS is currently focused on the individual warrior. Current research is directed at applications within naval tactical fighter aircraft.¹ However, this taxonomy may be applied to all human-technology interfaces, and systems of these interfaces. A ship's Combat Information Center is an excellent candidate, as is the Flag Plot of a battle group commander. Integration within the advanced C4I architectures promises a truly joint application achieving complete transparent interoperability for the service components which make up a JTF. By themselves, these architectures promise everything and deliver nothing. Careful and comprehensive attention must be focused on the warrior — the human element.

¹The reader's attention is directed to Harris, et al. (1991), and their work with the F-14D.

By virtue of the maelstrom of change surrounding the world today, the warrior is in a position to demand information and C2 assets tailored to his unique needs. The idea of a fleet or army is passé; information needs [access, manipulation, display] must now be directed to the lowest common denominator — the individual warrior. The warrior's role changes. He begins to make his own rules and define his own battlespace. He transitions from the controlled to the empowered. He begins to think about technology in terms of finding solutions to problems he does not know he has, or to do things that he was previously unable to envision. This is the essence of the KOALAS structure of intelligent control, innovative use of information technology, and intuition — redefining the probable, and achieving the impossible.

APPENDIX A

GLOSSARY OF TERMS

Acquisition of Knowledge: Obtaining the knowledge needed by an expert program. In certain domains, programs may be able to "learn" through experience, but typically the system designers and the experts being modeled must work closely together to identify and verify the knowledge of the domain. There has been some experience devising programs that actually bring the expert to the computer terminal where a "teaching session" can result in direct transfer of knowledge from the expert to the system itself. (Shortliffe, 1983)

Activation Mechanism : The situation required to invoke a procedure - usually a match of the system state to the preconditions required to exercise a production rule. (Gevarter, 1985)

Algorithm : A procedure for solving a problem in a finite number of steps. A procedure with a specific beginning and end that is guaranteed to solve a specific problem. A step-by-step search, where improvement is made in every step until the best solution is found. (Gevarter, 1985)

Analogical Reasoning : Determining the outcome of a problem by the use of analogies. A procedure for drawing conclusions about a problem by using past experience. (Turban, 1990)

Application Generator : A very high-level programming language in which programmers specify, through an interactive dialog with the system, which processing tasks are to be performed. (Long, Long, 1993)

Argument : That portion of a function which identifies the data to be operated on. (Long, Long, 1993)

Artificial Intelligence (AI) : i) discipline devoted to developing and applying computational approaches to intelligent behavior. Also referred to as machine intelligence or heuristic programming. (Gevarter, 1985) ii) The subfield of computer science that is concerned with symbolic reasoning and problem solving. (Turban, 1990) iii) Technology intended to design and to produce "intelligent" computer systems, that is, computers that can imitate human thought processes, yet attain more accurate results. To provide a common baseline, AI is defined as the application of knowledge, thought and learning to computer systems to aid humans. All areas of AI are basically involved in either the extraction or the generation of information and in understanding the surrounding environment. (Daniels, 1987) iv) The ability of a computer to reason, to learn, to strive for self-improvement, and to simulate human sensory capabilities. (Long, Long, 1993)

Artificial Intelligence Approach : An approach that has as its emphasis symbolic processes for representing and manipulating knowledge in a problem-solving mode. (Gevarter, 1985)

Assistant System : A type of knowledge-based system that helps users make relatively straightforward decisions. (Long, Long, 1993)

Associative Memory Technology : An experimental computer technology that attempts to build computers that will operate like a human brain. The machines possess simultaneous memory storage, and work with ambiguous information. (Turban, 1990)

Asynchronous Transmission : Data transmission at irregular intervals that is synchronized with start/stop bits. (Long, Long, 1993)

Atom : an individual. A proposition in logic that cannot be broken down into other propositions. An indivisible element. (Gevarter, 1985)

Attribute : A field in a relational database. (Long, Long, 1993)

Automation : The automatic control and operation of machines, processes, and procedures. (Long, Long, 1993)

Autonomous : A system capable of independent action. (Gevarter, 1985)

Back-End Processor : A host-subordinate processor that handles administrative tasks associated with retrieval and manipulation of data. (Long, Long, 1993)

Backtracking : i) Returning (usually due to depth-first search failure) to an earlier point in a search space. Also a name given to depth-first backward reasoning. (Gevarter, 1985) ii) A technique used in tree searches. The process works backward from a failed objective or an incorrect result to examine unexplored alternatives. (Turban, 1990)

Backward Chaining : i) A form of reasoning starting with a goal and recursively chaining backward to its antecedent goals or states by applying applicable operators until an appropriate earlier state is reached or the system backtracks. This is a form of depth-first search. When the application of operators changes a single goal or state into multiple goals or states, the approach is referred to as a problem reduction. ii) a search technique that starts from a desired goal or solution and attempts to reason backward toward known facts to prove the goal true. (Gevarter, 1985) iii) A search technique used in production ("if-then" rule) systems that begins with the action clause of a rule and works "backward" through a chain of rules in an attempt to find a verifiable set of condition clauses. (Turban, 1990)

Baud : i) A measure of the maximum number of electronic signals that can be transmitted via a communications channel. ii) Bits per second. (Long, Long, 1993)

Benchmark Test : A test for comparing the performance of several computer systems while running the same software, or comparing the performance of several programs that are run on the same computer. (Long, Long, 1993)

Blackboard Approach : A problem solving approach whereby the various system elements communicate with each other via a common working data storage called a blackboard. (Gevarter, 1985)

Blackboard Architecture : A software technique used to facilitate sharing of information between multiple expert systems operating cooperatively. (Gevarter, 1985)

Blind Search : i) An ordered approach that does not rely on knowledge for searching for a solution. (Gevarter, 1985) ii) A search approach that makes use of no knowledge or heuristics to help speed up the search process. A time-consuming and arbitrary search process that attempts to exhaust all possibilities. (Turban, 1990)

Blocks World : A small artificial world, consisting of blocks and pyramids, used to develop ideas in computer vision, robotics, and natural language interfaces. (Gevarter, 1985)

Bottom-Up Control Structure : A problem solving approach that employs forward reasoning from current or initial conditions. Also referred to as an event-driven or data-driven control structure. (Gevarter, 1985)

Breadth-First Search : i) An approach in which, starting with the root node, the nodes in the search tree are generated and examined level by level (before proceeding deeper). This approach is guaranteed to find an optimal solution if it exists. (Gevarter, 1985) ii) A search technique that evaluates every item at a given level of the search space before proceeding to the next level. (Turban, 1990)

Bridge : A protocol-independent hardware device that permits communication between devices on separate local area networks. (Long, Long, 1993)

Case-Based Reasoning : Based on the notion of that past experiences and case histories can often provide insights into future decisions/problem solving. A case is any set of features or attributes that are related in some manner and to which a comparison can be made of a current situation. The basis for the comparison is similarity — to what extent is the current situation similar to or analogous to prior situations (cases). The criteria for assessing similarity is varied and is a topic of current research. Similarity criteria include: nearest neighbor techniques, inductive techniques (ID3) and hybrid techniques which may include some elements of knowledge/intelligence. The challenge in case-based reasoning is to establish appropriate indices that allow comparison between and referencing of the various cases and the current scenario/situation. Case-Based reasoning is not as restrictive as rule-based systems in the sense of having to work out all the paths in the rule base prior to utilizing the system. Case-Based reasoning also can provide some adaptiveness to new situations and modify the case-histories based on new information. Case-Based reasoning systems have been substituted for expert systems, neural nets and other machine learning approaches. (Watkins, 1992)

Channel : The facility by which data are transmitted between locations in a computer network. (Long, Long, 1993)

Channel Capacity : The number of bits that can be transmitted over a communications channel per second. (Long, Long, 1993)

Chunk of Information : A collection of facts stored and retrieved as a single unit. The limitations of working memory are usually defined in terms of the number of chunks that can be handled simultaneously. (Turban, 1990)

Complex Instruction Set Computer (CISC) : A computer design architecture that offers programmers a wide variety of instructions. (Long, Long, 1993)

Classification Model : A model used in building expert systems that uses production rules and covers a highly bounded problem. (Turban, 1990)

Cognitive Style : The subjective process through which individuals organize and change information during the decisionmaking process. (Turban, 1990)

Cognition : an intellectual process by which knowledge is gained about perceptions or ideas. (Gevarter, 1985)

Common Sense : the ability to act appropriately in everyday situations based on one's lifetime accumulation of experiential knowledge. (Gevarter, 1985)

Commonsense Reasoning : low-level reasoning based on a wealth of experience. (Gevarter, 1985)

Computational Logic : a science designed to make use of computers in logic calculus. (Gevarter, 1985)

Computer Architecture : the manner in which various computational elements are interconnected to achieve a computational function. (Gevarter, 1985)

Computer Vision (Computational or Machine Vision) : perception by a computer, based on visual sensory input, in which a symbolic description is developed of a scene depicted in an image. It is often a knowledge-based, expectation-guided process that uses models to interpret sensory data. Used somewhat synonymously with image understanding and scene analysis. (Gevarter, 1985)

Conceptual Dependency : An approach to natural language understanding in which sentences are translated into basic concepts expressed as a small set of semantic primitives. (Gevarter, 1985)

Conflict Resolution : Selecting a procedure or rule from a conflict set of applicable competing procedures or rules. (Gevarter, 1985)

Conflict Set : The set of rules that matches some data or pattern in the global data base. (Gevarter, 1985)

Connectivity : Pertains to the degree to which hardware devices, software, and databases can be functionally linked to one another. (Long, Long, 1993)

Constraint Propagation : A method for limiting search by requiring that certain constraints be satisfied. It can also be viewed as a mechanism for moving information between subproblems. (Gevarter, 1985)

Context : The set of circumstances or facts that define a particular situation, event, and so on. The portion of the situation that remains the same when an operator is applied in a problem-solving situation. (Gevarter, 1985)

Control Structure : Reasoning strategy. The strategy for manipulating the domain knowledge to arrive at a problem solution. (Gevarter, 1985)

Cooperative Computing : An environment in which businesses cooperate internally and externally to take full advantage of available information and to obtain meaningful, accurate, and timely information. (Long, Long, 1993)

Cyberspace : A completely spatialized visualization of all information in global information processing systems, along pathways provided by present and future communications networks, enabling full co-presence and interaction of multiple users, allowing input and output from and to the full human sensorium, permitting simulations of real and virtual realities, remote data collection and control through tele-presence, and total integration and inter-communication with a full range of intelligent products and environments in real space. (Novak, 1991)

Data Base : i) An organized collection of data about some subject. (Gevarter, 1985) ii) The organizing of files into related units that are then viewed as a single storage concept. The data are then made available to a wide range of users. (Turban, 1990)

Data Base Management System : i) A computer system for the storage and retrieval of information about some domain. (Gevarter, 1985) ii) The software to establish, update, or query a database. (Turban, 1990)

Data-Driven : a forward-reasoning, bottom-up problem-solving approach. (Gevarter, 1985)

Data Structure : the form in which data are stored in a computer. (Gevarter, 1985)

Decision Making : Involves identifying and configuring relevant facts, formulating problem elements, defining solution alternatives, and choosing the best alternative. In supporting a decision making process, the way information is communicated to users plays a significant role. There exist three broad categories on display modes of information: cognitive aspects, screen design, and decision tasks. (Yazici, et al., 1992)

Decision Styles : The manner in which decisionmakers think and react to problems. It includes their perceptions, cognitive responses, values, and beliefs. (Turban, 1990)

Decision Support System (DSS) : i) A computer-based support system for management decision makers who deal with semi-structured problems that would not be amenable to management science optimization models per se. Comprised of four components: Data Base Management System (DBMS), Model Management System (MMS), Knowledge Base System (KBS) or Expert System (ES), and (dialog) or communication or user interface subsystem. DSSs are a potential link with the environmental realities the user copes with in formulating and carrying out decision related tasks. The actual power and scope of a DSS can only benefit a user if it is accessible and comprehensible. (Yazici, et al., 1992) ii) Computer-based information systems that combine models and data in an attempt to solve nonstructured problems with extensive user involvement. (Turban, 1990) iii) An interactive information system that relies on an integrated set of user-friendly hardware and software tools to produce and present information targeted to support management decision making involving semistructured and unstructured problems. (Long, Long, 1993)

Decision Tree : A graphical presentation of a sequence of interrelated decisions to be made under assumed risk. (Turban, 1990)

Declarative Knowledge Representation : Representation of facts and assertions. (Turban, 1990)

Deduction : *Logic.* a. a process of reasoning in which a conclusion follows necessarily from the premises presented. b. a conclusion reached by this process.

Deductive : Based on deduction from accepted premises. DEDUCTIVE and INDUCTIVE refer to two distinct logical processes. DEDUCTIVE reasoning is a logical process in which a conclusion drawn from a set of premises contains no more information than the premises taken collectively. *All dogs are animals; this is a dog; therefore, this is an animal;* The truth of the conclusion is dependent only on the method. *All men are apes; this is a man; therefore, this is an ape;* The conclusion is logically true, although the premise is absurd. INDUCTIVE reasoning is a logical process in which a conclusion is proposed that contains more information than the observations or experiences on which it is based. *Every crow that has ever been seen is black; all crows are black:* The truth of the conclusion is verifiable only in terms of future experience and certainty is attainable only if all possible instances have been examined. In the example, there is no certainty that a white crow will not be found tomorrow, but experience would make such an occurrence seem extremely unlikely.

Deductive Reasoning : In logic, reasoning from the general to the specific. Conclusions follow premises. Consequent reasoning. (Turban, 1990)

Deep Model : A model that captures all the forms of knowledge used by experts in their reasoning. (Turban, 1990)

DELPHI : A qualitative forecasting methodology using anonymous questionnaires. Effective for technological forecasting and forecasting involving sensitive issues. (Turban, 1990)

Demon : A procedure that is automatically activated if a specific, predefined state is recognized. (Turban, 1990)

Depth-First Search : i) A search that proceeds from the root node to one of the successor nodes and then to one of that node's successor nodes, and so on, until a solution is reached or the search is forced to backtrack. (Gevarter, 1985) ii) A search procedure that explores each branch of a search tree to its full vertical length. Each branch is searched for a solution and if none is found, a new vertical branch is searched to its depth, and so on. (Turban, 1990)

Descriptive Models : Models that describe things as they are. (Turban, 1990)

Deterministic Models : Models that are constructed under assumed certainty, namely, there is only one possible (and known) result to each alternative course or action. (Turban, 1990)

Dialog Generation and Management System (DGMS) : A software management package in a DSS whose functions in the dialog subsystem is similar to that of a DBMS in a database. (Turban, 1990)

Dialog Style : The combination of the action languages, the display language, and knowledge base which determines input and provides output. Examples of styles include menu-driven and command language. (Turban, 1990)

Dialog System : The hardware and software that provide the user interface for DSS. It also includes the ease-of-use, accessibility, and human-machine interface. (Turban, 1990)

Difference Reduction : "Means-ends" analysis. An approach to problem solving that tries to solve a problem by iteratively applying operators that will reduce the difference between the current state and the goal state. (Gevarter, 1985)

Directed Graph : a knowledge representation structure consisting of nodes (representing, e.g., objects) and directed connecting arcs (labeled edges, representing, e.g., relations). (Gevarter, 1985)

Disproving : an attempt to prove the impossibility of a hypothesized conclusion (theorem) or goal.

Distributed Data Processing : Both a technological and an organizational concept based on the premise that information systems can be made more responsive to users by moving computer hardware and personnel physically closer to the people who use them. (Long, Long, 1993)

Domain : the problem area of interest: for example, bacterial infections, prospecting, VLSI design. (Gevarter, 1985)

Domain Expert : A person with expertise in the domain in which the expert system is being developed. The domain expert works closely with the knowledge engineer to capture the expert's knowledge in a knowledge base. (Turban, 1990)

Dynamic Model(s) : Models whose input data are being changed over time. (Turban, 1990)

Editor : A software tool to aid in modifying a software program. (Gevarter, 1985)

Extended Industry Standard Architecture (EISA) : An architecture for microprocessors that use the Intel microprocessors. (Long, Long, 1993)

Emulate : To perform like another system. (Gevarter, 1985)

Equivalent : Has the same truth value (in logic). (Gevarter, 1985)

Evaluation Function : A function (usually heuristic) used to evaluate the merit of the various paths emanating from a node in a search tree. (Gevarter, 1985)

Event-Driven : A forward-chaining problem-solving approach based on the current problem status. (Gevarter, 1985)

Executive Information Systems (EIS) : Computerized systems that are specifically designed to support executive work. (Turban, 1990)

Executive Support System : i) An executive information system that includes some analytical capabilities. (Turban, 1990) ii) A system designed specifically to support decision making at the strategic level. (Long, Long, 1993)

Expectation-Driven : processing approaches that proceed by trying to confirm models, situations, states, or concepts anticipated by the system. (Gevarter, 1985)

Expert System(s) : i) The traditional system architecture of a knowledge base, an inference engine, and a user interface. (Dos Santos, et al., 1992) ii) A computer program that uses knowledge and reasoning techniques to solve problems normally requiring the abilities of human experts. iii) A computer program using facts and procedures to emulate the reasoning process of human experts in solving particular types of problems. (Gevarter, 1985) iv) Designed to capture problem-solving and decision-making processes which are carried out by an expert well versed in both the theory and practice of the problem context. Can be described as problem-solving computer programs that can reach a level of performance comparable to that of a human expert in some specialized domain. ESs interact with human decision-makers, and are based on the premise that to make the programs more powerful, it is necessary to identify, capture and encode knowledge that is critical for problem-solving and decision-making. (Walden, 1992) v) A computer system that applies reasoning methodologies on knowledge in a specific domain in order to render advice or recommendations, much like a human expert. A computer system that achieves high levels of performance in task areas that, for human beings, require years of special education and training. (Turban, 1990) vi) An interactive knowledge-based system that responds to questions, asks for clarification, makes recommendations, and generally helps users make complex decisions. (Long, Long, 1993)

Expertise : The set of capabilities that underlies the performance of human experts, including extensive domain knowledge, heuristic rules that simplify and improve approaches to problem-solving, metaknowledge and metacognition, and compiled forms of behavior that afford great economy in skilled performance. (Turban, 1990)

Expert System Interface Manager (ESIM) : Has a knowledge base comprised of facts about user characteristics, display preferences, decision tasks, other relevant factors, and rules to select appropriate display formats. (Yazici, et al., 1992)

Explanation Capabilities : Knowledge engineering has come to include the development of techniques for making explicit the basis for recommendations or decisions. This requirement tends to constrain the methods of inference and the knowledge representation that is used by a complex reasoning program. (Shortliffe, 1983)

Explanation Facility : i) A feature of expert systems that provides a rationale for the conclusions reached by the system. It usually provides an unraveling of the sequence of steps in the search process along with additional information designed to improve human understanding. (Gevarter, 1985) ii) The component of an expert system that can explain the system's reasoning and justify its conclusions. (Turban, 1990)

Fault-Tolerance : A computing system that continues to operate satisfactorily in the presence of faults. (Turban, 1990)

Fifth-Generation Computer : i) A non-von Neumann, intelligent, parallel-processing form of computer now being pursued by Japan. (Gevarter, 1985) ii) The research project in which the Japanese are investigating parallel processing and other advanced computing techniques in an attempt to develop a "fifth generation" of computer systems, which will be both efficient and intelligent. (Turban, 1990)

Fifth-Generation Languages : Artificial Intelligence languages such as Lisp and PROLOG and their variants.

Firmware : Logic for performing certain computer functions that is built into a particular computer by the manufacturer. (Long, Long, 1993)

First-Order Predicate Logic : A popular form of logic used by the AI community for representing knowledge and performing logical inference. First-order predicate logic permits assertions to be made about variables in a proposition. (Gevarter, 1985)

Flexibility in DSS : System ability to react to changes in the environment, tasks, or user of the DSS. It is the ability to modify, adapt, solve problems, and evolve. (Turban, 1990)

Forward Chaining : i) Event-driven or data-driven reasoning. ii) A search technique that begins with known facts or data and attempts to reason toward a goal or solution. (Gevarter, 1985)

Fourth-Generation Languages (4GLs) : Nonprocedural, user-oriented languages that enable quick programming by specifying only the desired result. (Turban, 1990)

Frame : i) A data structure for representing stereotyped objects or situations. A frame has slots to be filled for objects and relations appropriate to the situation. (Gevarter, 1985) ii) A knowledge representation scheme that associates one or more features with an object in terms of various slots and particular slot values. (Turban, 1990)

Frame-Based Systems : An expert system which have a knowledge base consisting of concepts represented in object hierarchies with higher order concepts subsuming lower order concepts. Rules may be present in these systems but the knowledge base is predominantly comprised of frames/concepts. (Watkins, 1992)

Functional Application : The generic task or function performed in an application. (Gevarter, 1985)

Function-Based Information System : An information system designed for the exclusive support of a specific application area, such as inventory management or accounting. (Long, Long, 1993)

Fuzzy Logic : i) Systems in which the inference mechanism for dealing with uncertainty is not restricted to certainty factors, probability, scoring models or other common methods based on Aristotelian logic. Rather, with fuzzy logic which is based on fuzzy set theory, an attribute or item can have partial membership in more than one set and in sets which appear to be contradictory. In essence, fuzzy sets may represent a continuous range of possible states for values in and out of sets which are numerically represented. Fuzzy systems often include rules from expert systems and attributes of neural sets. Thus they can process structure knowledge numerically. (Watkins, 1992) ii) Ways of reasoning that can cope with uncertain or partial information; characteristic of human thinking and many expert systems. (Turban, 1990)

Fuzzy Set : A generalization of set theory that allows for various degrees of set membership, rather than all or none. (Gevarter, 1985)

General Problem Solver (GPS) : The first problem solver (1957) to separate its problem-solving methods from knowledge of the specific task being considered. The GPS problem-solving approach employed was "means-ends analysis." (Gevarter, 1985)

Generate and Test : A common form of state-space search based on reasoning by elimination. The system generates possible solutions and the tester prunes those solutions that fail to meet appropriate criteria. (Gevarter, 1985)

Genetic Algorithms : i) An algorithm that exploits the evolutionary forces behind Darwin's theory of natural selection. The general idea behind genetic algorithms is to create a starting population of rules, find the better performing rules, and create new rules by recombining or mutating the components of the "parent" rules. This process will generate a large set of rules - the stronger rules stay and become parents, the weaker rules are discarded or die off. The two main breeding operators are crossover and mutation. Crossover interchanges portions of two rule strings at a random point, leading to two new rules to be evaluated. Mutation is more of a minor operation in which a random value is changed in a rule string. The process of creating rules, evaluating rules, and breeding new rules continues until either a set performance level is achieved, or a certain number of generations have been produced. (Sandman, 1992) ii) An algorithm that allows machine learning and natural selection to take place especially in neural networks and to facilitate adaptability of the networks to adjust to new situations. Genetic algorithms are still somewhat developmental and experimental but appear to have potential to provide learning capability to neural networks and other kinds of algorithms. (Watkins, 1992)

Global Data Base : Complete data base describing the specific problem, its status, and that of the solution process. (Gevarter, 1985)

Goal-Driven : A problem-solving approach that works backward from the goal. (Gevarter, 1985)

Goal Regression : A technique for construction a plan by solving one conjunctive subgoal at a time, checking to see that each solution does not interfere with the other subgoals that have already been achieved. If interferences occur, the offending subgoal is moved to an earlier noninterfering point in the sequence of subgoal accomplishments. (Gevarter, 1985)

Goal-Seeking : The capability of asking the computer what values certain variables must have in order to attain desired goals. (Turban, 1990)

Graphical User Interface (GUI) : Software that permits users to select processing options simply by positioning an arrow over a graphic representation of the desired function or program. (Long, Long, 1993)

Heuristic Search Technique : Graph searching methods that use heuristic knowledge about the domain to help focus the search. They operate by generating and testing intermediate states along potential solution paths. (Gevarter, 1985)

Heuristics : i) Rules of thumb or empirical knowledge used to help guide a problem solution. ii) A rule of thumb that applies in most cases, but is not guaranteed to lead to a solution. Such information usually is supplied by an expert based on experience in solving particular problems. (Gevarter, 1985) iii) The informal, judgmental knowledge of an application area that constitutes the "rules of good judgment" in the field. Heuristics also encompass

the knowledge of how to solve problems efficiently and effectively, how to plan steps in solving a complex problem, how to improve performance, and so forth. (Turban, 1990)

Hierarchical Database : A database whose organization employs the tree data structure. (Long, Long, 1993)

Hierarchical Planning : A planning approach in which first a high-level plan is formulated considering only the important (or major) aspects. Then the major steps of the plan are refined into more detailed subplans. (Gevarter, 1985)

High-level Languages : Computer programming languages that approximate the use of the English language or mathematical functions and can be used on a variety of computers. Examples are: COBOL, PASCAL, FORTRAN, Ada, and "C." (Turban, 1990)

Hierarchy : a system of things ranked one above the other. (Turban, 1990)

Human Factors Technology : Physiological, psychological, and training factors to be considered in the design of hardware and software and the development of procedures to ensure that humans can interface with machines efficiently and effectively. (Turban, 1990)

Hybrid Environment : A software package for expediting the construction of expert systems that includes several knowledge representation schemes. (Turban, 1990)

Hypermedia : i) Combination of several types of media such as text, graphics, audio, and video. (Turban, 1990) ii) Software that enables the integration of data, text, graphics, sounds of all kinds, and full-motion video. (Long, Long, 1993)

Hypertext : i) An approach for handling text and other information by allowing the user to jump from a given topic, whenever he wishes, to related topics. It allows access to information in a nonlinear fashion by following a train of thought. (Turban, 1990) ii) Data management software that provides links between key words in the unstructured text-based documents. (Long, Long, 1993)

Icon : A visual, graphic representation of an object, word, or object. (Turban, 1990)

Iconic Model : A physical, scaled replica. (Turban, 1990)

Idea Processor : A software productivity tool that allows the user to organize and document thoughts and ideas. (Long, Long, 1993)

Identity : Two propositions (in logic) that have the same truth value. (Gevarter, 1985)

"If - Then" : A conditional rule in which a certain action is taken only if some condition is satisfied. (Turban, 1990)

Image Understanding (IU) : Visual perception by a computer employing geometric modeling and the AI techniques of knowledge representation and cognitive processing to develop scene interpretations from image data. IU has dealt extensively with three-dimensional objects. (Gevarter, 1985)

Implies : A connective in logic that indicates that if the first statement is true, the statement following is also true. (Gevarter, 1985)

Individual : A nonvariable element (or atom) in logic that cannot be broken down further. (Gevarter, 1985)

Induction : *Logic.* a. any form of reasoning in which the conclusion though supported by the premises, does not follow from them necessarily. b. the process of estimating the validity of observations of part of a class of facts as evidence for a proposition about the whole class. c. a conclusion reached by this process.

Induction Algorithm(s) : Attempt to develop a procedure by which the class of an object can be determined from the values of its attributes (inputs). The developed procedure is represented as a decision tree. The leaves of the tree are class names; other nodes represent tests on inputs. Each branch emerging from a node represents a possible values for the input tested at that node. Most often, induction algorithms develop trees which continue to test inputs until the untested inputs provide no further information to help separate among the classes. (Dos Santos, et al., 1992)

Induction Support Systems (ISS) : An interactive computer system designed to assist a decision maker and/or knowledge base developer in deriving classification rules from a training set of examples. An ISS incorporates decision aids intended to assist in the process of decision channeling. Decision channeling has been identified as the general property of an interface architecture that serves to support and shift the decision process. Induction systems have been recognized as a useful approach for converting data to knowledge. (Sandman, 1992)

Inductive Expert System(s) : Developed using an induction algorithm on a set of data obtained from past experiences. Induction algorithms attempt to acquire expert knowledge without the direct involvement of humans. Two major reasons:

1. Human experts often are scarce and expensive.
2. Experts often find it difficult to articulate their knowledge, so knowledge acquisition techniques which rely upon experts verbalizing their knowledge can be time consuming and may not result in the acquisition of expert knowledge. (Dos Santos, et al., 1992)

Inductive Reasoning : In logic, reasoning from the specific to the general. Conditional or antecedent reasoning. (Turban, 1990)

Inexact (Approximate) Reasoning : Used when the expert system has to make decisions based on partial or incomplete information. (Turban, 1990)

Infer : i. to derive by reasoning; conclude or judge from premises or evidence. ii. (of facts, circumstances, statements, etc.) to indicate or involve as a conclusion.

Inference : i) The process of reaching a conclusion based on an initial set of proposition, the truths of which are known or assumed. ii) The process of drawing a conclusion from given evidence. To reach a decision by reasoning.

Inference Engine : i) Another name given to the control structure of an AI problem solver in which the control is separate from the knowledge. ii) The part of an expert system that controls the selection of rules and their application to data in searching for a solution of a

problem. (Gevarter, 1985) iii) The part of an expert system that actually performs the reasoning function. (Turban, 1990) iv) Controls the evaluation of a problem and evaluates the rules in the knowledge base to define a solution. A common control method is to chain through the "if-then" rules to form the conclusion. The basic methods are top-down (forward chaining), bottom-up (backward chaining) or a combination of the two. (Daniels, 1987)

Inference Tree : A schematic view of the inference process that shows the order in which rules are being tested. (Turban, 1990)

Information Engineering : A term coined to emphasize using the rigors of engineering discipline in the handling of the information resource. (Long, Long, 1993)

Information Fusion : The process of correlating, analyzing and integrating information originating from remote collection sources (I would argue that remote is not a necessary condition). Information collected on the battlefield is voluminous and overwhelming. Efforts have been aimed at filtering the critical intelligence data from the noncritical data and at expediting the intelligence needed most by commanders. (Daniels, 1987)

Information for Motivation : A process for the development and use of EIS, starting with the determination of success factors and ending with a motivation program based on goal attainment. (Turban, 1990)

Information Overload : The circumstance that occurs when the volume of information is so great that the decisionmaker cannot distinguish relevant from irrelevant information. (Long, Long, 1993)

Inheritance : The process by which one object takes on or is assigned the characteristics of another object higher up in a hierarchy. (Turban, 1990)

Instantiation : i) Replacing a variable by an instance (an individual) that satisfies the system (or satisfies the statement in which the variable appears). (Gevarter, 1985) ii) The process or assigning (or substituting) a specific value or name to a variable in a frame (or in a logic expression) making it a particular "instance" of that variable. (Turban, 1990)

Intelligence : The degree to which an individual can successfully respond to new situation or problems. It is based on the individual's knowledge level and the ability to appropriately manipulate and reformulate that knowledge (and incoming data) as required by the situation or problem. (Gevarter, 1985)

Intelligent Agents : Software creations that incorporate AI concepts. These constructs will maneuver through the information infrastructure to locate information relative to a user's requests.

Intelligent Assistant : an AI computer program (usually an expert system) that aids a person in the performance of a task. (Gevarter, 1985)

Intelligent Computer-Aided Instruction (ICAI) : Using AI techniques for training or teaching with a computer. (Turban, 1990)

Interactive : Pertaining to on-line and immediate communication between the end user and computer. (Long, Long, 1993)

Interactive Visual Decision Making (IVDM) : Graphic animation in which systems and processes are presented dynamically to the decisionmaker. It enables visualization of the results of different potential actions. (Turban, 1990)

Interactive Visual Simulation : A special case of IVDM in which a simulation approach is used in the decisionmaking process. (Turban, 1990)

Interactive Environment : A computational system in which the user interacts (dialogues) with the system (in real time) during the process of developing or running a computer program. (Gevarter, 1985)

Interdependent Decisions : A series of decisions that are interrelated. Sequential decisions are usually interdependent. (Turban, 1990)

Interface : i) The system by which the user interacts with the computer. In general, the junction between two components. (Gevarter, 1985) ii) The portion of a computer system that interacts with the user, accepting commands from the computer keyboard and displaying the results generated by other portions of the computer system. (Turban, 1990)

Intuition : i) Immediate apprehension or cognition. ii) knowledge or conviction gained by intuition. iii) The power or faculty of attaining direct knowledge or cognition without evident rational thought or inference. iv) Quick and ready insight.

Invoke : To place into action (usually) by satisfying a precondition. (Gevarter, 1985)

Knowledge : Understanding, awareness, or familiarity acquired through education or experience. Anything that has been learned, perceived, discovered, inferred, or understood. The ability to use information. (Turban, 1990)

Knowledge Acquisition : A highly complex process and it all comes down to good human communication skills, analytic ability and a lot of common sense. (Walden, 1992)

Knowledge Acquisitioner : The person who performs knowledge acquisition collects and updates the rules in the knowledge base. He or she also ensures that the knowledge base has correct information in it and that the rules work together properly. (Turban, 1990)

Knowledge Base : i) AI data bases that are not merely files of uniform content, but collections of facts, inferences, and procedures corresponding to the types of information needed for problem solution. (Gevarter, 1985) ii) The most common method of representing knowledge is through the use of rules about a specific domain of information. These rules include both facts and heuristic rules. Facts are known rules concerning the domain of information. Heuristic rules are those rules of good/better judgment developed through trial-and-error methods by domain experts while solving problems. More recently developed methods of representing knowledge are the use of frames and scripts. Frames consist of a package of data with slots for objects and relationships. Scripts are framelike structures representing a sequence of typical steps of a particular function. (Daniels, 1987) iii) The foundation of a knowledge-based system that contains facts, rules, inferences, and procedures. (Long, Long, 1993)

Knowledge Base Management : Management of a knowledge base in terms of storing, accessing, and reasoning with the knowledge. (Gevarter, 1985)

Knowledge Based System : A computer-based system, often associated with artificial intelligence, that helps users make decisions by enabling them to interact with a knowledge base. (Long, Long, 1993)

Knowledge Engineer : i) A specialist in extracting and in encoding the knowledge required to implement an expert system. (Gevarter, 1985) ii) An AI specialist responsible for the technical side of developing an expert system. The knowledge engineer works closely with the domain expert to capture the expert's knowledge in a knowledge base. (Turban, 1990)

Knowledge Engineering : i) The AI approach focusing on the use of knowledge (e.g., as in expert systems) to solve problems. (Gevarter, 1985) ii) The engineering discipline whereby knowledge is integrated into computer systems in order to solve complex problems normally requiring a high level of computer expertise. (Turban, 1990)

Knowledge Interface: The mechanical interface between the expert program and the individual who is using it. Researcher's on these systems are also looking for ways to combine AI techniques with more traditional numerical approaches produce enhanced system performance. There is growing recognition that the greatest power in knowledge-based expert systems may lie in the melding of AI techniques and other computer science methodologies. (Shortliffe, 1983)

Knowledge Refining : The ability of the program to analyze its own performance, learn, and improve itself for future consultation. (Turban, 1990)

Knowledge Representation (KR) : The form of the data structure used to organize the knowledge required for a problem. (Gevarter, 1985)

Knowledge Source : An expert system component that deals with a specific area or activity. (Gevarter, 1985)

Knowledge System : Computer systems that embody knowledge, include inexact, heuristic, and subjective knowledge; the results of knowledge engineering. (Turban, 1990)

Language Processor : Parses and interprets questions from the user and formats the question for the inference engine. When a result is reached, the language processor then formats the information for its display to the user. (Daniels, 1987)

Learning : The application of learning in AI has evolved in three stages. 1) an attempt to develop systems that modified themselves to adapt to their environments. 2) this stage viewed learning as a large a complex process; a system could not be expected to "learn" without some sort of knowledge base with which to start. Thus, small learning problems were studied in detail, and large amounts of knowledge were incorporated into the learning systems. 3) currently, the need to acquire knowledge for expert systems and the third phase. There are four views of what learning is: i) a process by which a system improves its performance; ii) the acquisition of explicit knowledge; iii) skill acquisition; and iv) theory formation, hypothesis formation and inductive inference. A learning process involves a person who performs knowledge acquisition, obtaining information from the

environment to make improvements on a knowledge base. An inference engine, which uses the knowledge base to solve problems, also provides feedback to the learning element to make adjustments to the knowledge base. (Daniels, 1987)

Least Commitment : A technique for coordinating decision making with the availability of information, so that problem-solving decisions are not made arbitrarily or prematurely, but are postponed until there is enough information. (Gevarter, 1985)

LISP : List Processing Language; the basic AI programming language. (Gevarter, 1985)

Logical Operation(s) : i) Execution of a single computer instruction. (Gevarter, 1985) ii) Computer operations that make comparisons between numbers and between words, then perform appropriate functions, based on the results of the comparison. (Long, Long, 1993)

Logical Representation : Knowledge representation by a collection of logical formulas (usually in first-order predicate logic) that provide description of the world.

Management Information System : An integrated structure of databases and information flow throughout all levels and components of an organization, whereby the collection, transfer, and presentation of information is optimized to meet the needs of the organization. (Long, Long, 1993)

Means-Ends Analysis : A problem-solving approach (used by GPS) in which problem-solving operators are chosen in an iterative fashion to reduce the difference between the current problem-solving state and the goal state. (Gevarter, 1985)

Meta-Knowledge : Knowledge in an expert system about how the system operates or reasons. More generally, knowledge about knowledge. (Turban, 1990)

Meta-Rule : A higher-level rule used to reason about lower-level rules. ii) rules about the use of other rules. They are used to improve the efficiency of application of rules in rule based systems. (Gevarter, 1985)

Methods of Inference : Closely linked to the issue of knowledge representation is the mechanism for devising a line of reasoning for a given consultation. Techniques for hypothesis generation and testing are required, as are focusing techniques such as the heuristic search methods mentioned above. Particularly challenging, is the development of techniques for quantifying and manipulating uncertainty. Although inferences can sometimes be based on established techniques such as Bayes' Theorem or decision analysis, utilization of expert judgmental knowledge typically leads to the development of alternate methods for symbolically manipulating inexact knowledge. (Shortliffe, 1983)

Model Base : A collection of preprogrammed quantitative models (e.g., statistical, financial, engineering, optimization) organized as a single unit. (Turban, 1990)

Model-Based Reasoning : Different from expert systems in the sense that the knowledge is not represented in terms of rules or frames but rather in the form of a model.. The model may be an abstraction of a human expert or a mathematical or other structured model which can provide problem/decision solution support. Model based reasoning may be an extension of management science/operations research techniques or it may involve other

model forms or abstractions. The idea is that rather than represent the state of the world for a given domain in terms of IF — THEN conditional statements which are logically related, we form an abstraction of the problem domain and its solution and provide the decision maker with the model based support tool. (Watkins, 1992)

Model Driven : A top-down approach to problem solving in which the inferences to be verified are based on the domain model used by the problem solver. (Gevarter, 1985)

Modus Ponens : A mathematical form of argument in deductive logic. It has the form:

If A is true, then B is true.
A is true.
Therefore, B is true. (Gevarter, 1985)

Monotonic Reasoning : A reasoning system based on the assumption that once a fact is determined it cannot be altered during the course of the reasoning process. (Turban, 1990)

Monte Carlo Simulation : A mechanism that uses random numbers in order to predict the behavior of an event whose probabilities are known. (Turban, 1990)

Natural Deduction : Informal reasoning. (Gevarter, 1985)

Natural Language : A natural language is a language spoken by humans on a daily basis, such as English, German, French, etc. (Turban, 1990)

Natural Language Interface (NLI) : A system for communicating with a computer by using a natural language. (Gevarter, 1985)

Natural Language Processing (NLP) : i) Processing of natural language (e.g., English) by a computer to facilitate communications with the computer or for other purposes, such as language translation. (Gevarter, 1985) ii) An older AI technology which has been envisioned as a key element in DSS. Natural language processing continues to improve in terms of parsing capabilities and although far from natural in a human sense has had some impressive successes in a variety of applications, particularly in text recognition systems. (Watkins, 1992) iii) An AI-based user interface that allows the user to carry on a conversation with a computer-based system in much the same way as he would converse with another human. (Turban, 1990)

Natural Language Understanding (NLU) : Response by a computer based on the meaning of a natural language input. (Gevarter, 1985)

Negate : To change a proposition into its opposite. (Gevarter, 1985)

Neural Networks : i) Consist of groups of cells and the connections between the cells. First developed in an attempt to simulate the functions of the visual cortex. The cells are autonomous processing units to which one can attach some semantic meaning. The connections between the cells indicate either a positive or negative association between the cells. Numerical weights are associated with each connection to show the strength of the association. Cells are activated when the weighted sum of the inputs exceeds some activation threshold designated for the cell. (Sandman, 1992) ii) Algorithms for detecting patterns in large amounts of data. The idea behind a neural network is that for a given set

of inputs and a desired set of outputs (to and from the neural net) a mapping relationship is established that enables new input data to be properly classified or identified according to the output criteria. Neural nets look at the relationships implicit in the data and develop a predictive model for use with further data. Neural nets do not provide criteria equivalent to statistical methods for evaluating the underlying model. As such developing an appropriate neural net tends to be more of an art and requires a great deal of data and "tinkering" with the model to achieve a satisfactory predictive model. Neural nets appear to have very good predictive and classifications abilities in a variety of domains. Unlike expert systems, they offer no explanation or provide insights into how the end result or solutions is achieved. (Watkins, 1992)

Nonmonotonic Logic : A logic in which results are subject to revision as more information is gathered. (Gevarter, 1985)

Nonprocedural Languages : The programmer specifies only the desired results rather than the detailed steps of how to get there. (Turban, 1990)

Object Oriented Language : A programming language structured to enable the interactions between user-defined concepts that contain data and operations to be performed on the data. (Long, Long, 1993)

Object Oriented Programming : i) A programming approach focused on objects that communicate by message passing. An object is considered to be a package of information and descriptions of procedures that can manipulate that information. (Gevarter, 1985) ii) A language for representing objects and processing those representations by sending messages and activating methods. (Turban, 1990)

Open Architecture : Refers to micros that give users the flexibility to configure the system with a variety of peripheral equipment. (Long, Long, 1993)

Operators : Procedures or generalized actions that can be used for changing situations. (Gevarter, 1985)

Optimization : Identification of the best possible solution. (Turban, 1990)

Packet Switching : A data communications process in which communications messages are divided into packets (subsets of the whole message), transmitted independent of one another in a communication network, then reassembled at the source. (Long, Long, 1993)

Parallel Processing : i) Simultaneous processing, as opposed to the sequential processing in a conventional (von Neumann) type of computer architecture. (Gevarter, 1985) ii) An advanced computer processing technique that allows the computer to perform multiple processes at the same time, in "parallel." (Turban, 1990) iii) A processing procedure in which one main processor examines the programming problem and determines what portions, if any, of the problem can be solved in pieces by other subordinate processors. (Long, Long, 1993)

Parser : A computer program for analyzing the syntactical structure of a text or a speech. (Gevarter, 1985)

Parsing : The process of breaking down a character string of natural language input into its component parts so that it can be more readily analyzed, interpreted, or understood. (Turban, 1990)

Path : A particular track through a state graph. (Gevarter, 1985)

Pattern Directed Invocation : The activation of procedures by matching their antecedent parts to patterns present in the global data base (the system status). (Gevarter, 1985)

Pattern Matching : i) Matching patterns in a statement or image against patterns in a global data base, templates, or models. (Gevarter, 1985) ii) The technique of matching an external pattern to one stored within a computer's memory, used in inference engines, image processing, speech recognition. (Turban, 1990)

Pattern Recognition : The process of classifying data into predetermined categories. (Gevarter, 1985)

Perception : An active process in which hypotheses are formed about the nature of the environment, or sensory information is sought to confirm or refute hypotheses. (Gevarter, 1985)

Personal AI Computer : New, small, interactive, stand-alone computers for use an AI researcher in developing AI programs. Usually specifically designed to run an AI language such as LISP. (Gevarter, 1985)

Plan : A sequence of actions to transform an initial situation into a situation satisfying the goal conditions. (Gevarter, 1985)

Portability : The ease with which a computer program developed in one programming environment can be transferred to another. (Gevarter, 1985)

Predicate : That part of a proposition that makes an assertion (e.g., states a relation or attribute) about individuals. (Gevarter, 1985)

Predicate Logic : A modification of propositional logic to allow the use of variables and functions of variables. (Gevarter, 1985)

Prefix Notation : A list representation (used in LISP programming) in which the connective, function, symbol, predicate is given before the arguments. (Gevarter, 1985)

Premise : A first proposition on which subsequent reasoning rests. (Gevarter, 1985)

Principle of Choice : The criterion for making a choice among alternatives. (Turban, 1990)

Problem Oriented Language : A high level language whose instruction set is designed to address a specific problem (such as a process control or simulation). (Long, Long, 1993)

Problem Reduction : A problem-solving approach in which operators are used to change a single problem into several subproblems (which are usually easier to solve). (Gevarter, 1985)

Problem Solving : A process in which one starts from an initial state and proceeds to search throughout a problem state in order to identify a desired goal. (Turban, 1990)

Problem State : The condition of the problem at a particular instant. (Gevarter, 1985)

Procedural Knowledge Representation : The representation of knowledge about the world by a set of procedures — small programs that know how to do specific things (how to proceed in well-specified situations). (Gevarter, 1985)

Procedure Oriented Language : A high-level language whose general purpose instruction set can be used to produce a sequence of instructions to model scientific and business procedures. (Long, Long, 1993)

Production Rule : i) A modular knowledge structure representing a single chunk of knowledge, usually in if-then or antecedent-consequent form. Popular in expert systems. (Gevarter, 1985) ii) A knowledge representation method in which knowledge is formalized into "rules" containing an IF (condition) part and a THEN (action) part. (Turban, 1990)

Programming Environment : The total programming setup, including the interface, the languages, the editors, and other programming tools. (Gevarter, 1985)

Programming in Logic (PROLOG) : A logic-oriented AI language developed in France and popular in Europe and Japan. (Gevarter, 1985)

Property List : A knowledge representation technique by which the state of the world is described by objects in the world via lists of their pertinent properties and their associated attributes and values. (Gevarter, 1985)

Proposition : A statement (in logic) that can be true or false. (Gevarter, 1985)

Propositional Logic : An elementary logic that uses argument forms to deduce the truth or falsehood of a new proposition from known propositions. (Gevarter, 1985)

Prototype : An initial model or system that is used as a base for constructing future models or systems. (Gevarter, 1985)

Pseudoreduction : An approach to solving the difficult problem case where multiple goals must be satisfied simultaneously. Plans are found to achieve each goal independently and then integrated using knowledge of how plan segments can be intertwined without destroying their important effects. (Gevarter, 1985)

Real Time : In synchronization with the actual occurrence of events; results are given rapidly enough to be useful in directly controlling a physical process or guiding a human user. (Turban, 1990)

Recursive Operations : Operations defined in terms of themselves. (Gevarter, 1985)

Reduced Instruction Set Computer (RISC) : A computer designed architecture based on a limited instruction set. (Long, Long, 1993)

Relational Database : i) A database whose records are organized into tables that can be processed by either relational algebra or relational calculus. (Turban, 1990) ii) A database in which data are accessed by content rather than by address. (Long, Long, 1993)

Relaxation Approach : An iterative problem-solving approach in which initial conditions are propagated utilizing constraints until all goal conditions are adequately satisfied. (Gevarter, 1985)

Relevant Backtracking (Dependency-Directed or Nonchronological Backtracking) : Backtracking (during a search) not to the most recent choice point, but to the most relevant choice point. (Gevarter, 1985)

Representation of Knowledge: A variety of methods for computer-based representation of human knowledge have been devised, each of which is directed at facilitating the associated symbolic reasoning and at permitting the codification and application of "common sense" knowledge of the domain, e.g., production rules, frames, and predicate calculus. (Shortliffe, 1983)

Resolution : A general, automatic, syntactic method for determining if a hypothesized conclusion (theorem) follows from a given set of premises (axioms). (Gevarter, 1985)

Risk Analysis : Analysis of decision situations in which results are dependent on events whose probabilities of occurrence are assumed to be known. (Turban, 1990)

Root Node : The initial (apex) node in a tree representation. (Gevarter, 1985)

Rule : A formal way of specifying a recommendation, directive, or strategy, expressed as IF premise and THEN conclusion. (Turban, 1990)

Rule Induction : Rules are created by a computer from examples of problems where the outcome is known. These rules are generalized to other cases. (Turban, 1990)

Rule Interpreter : The control structure for a production rule system. (Gevarter, 1985)

Rule-Based System : i) A form of expert system in which the procedural knowledge is encoded using "if-then" rules (production rules). (Gevarter, 1985) ii) An expert system with a knowledge base component consisting of conditional "if-then" statements which are generally "chained" together through some appropriate method of inference. The rules, once established in the knowledge base are static, non-adaptive and function identically in repetitive dialogues for a given problem/decision domain. (Watkins, 1992)

Satisficing : i) Developing a satisfactory, but not necessarily optimum solution. (Gevarter, 1985) ii) A process during which one seeks a solution that will satisfy a set of constraints. In contrast to optimization, which seeks the best possible solution; when one satisfices, one simply seeks a solution that will work. (Good Enough) (Turban, 1990)

Scenario : A statement of assumptions and configurations concerning the operating environment of a particular system at a particular time. (Turban, 1990)

Scheduling : Developing a time sequence for things to be done. (Gevarter, 1985)

Schema : A data structure for knowledge representation. Examples of schema are frames and rules. (Turban, 1990)

Scripts : Framelike structures for representing sequences of events. (Turban, 1990)

Search Space : The implicit graph representing all the possible states of the system which may have to be searched to find a solution. In many cases the search space is infinite. The term is also used for not-state-space representations. (Turban, 1990)

Semantic : Of or relating to meaning. (Gevarter, 1985)

Semantic Networks : i) A knowledge representation method consisting of a network of nodes, standing for concepts or objects, connected by arcs describing the relations between nodes. (Turban, 1990) ii) A knowledge representation for describing the properties and relations of objects, events, concepts, situations, or actions by a directed graph consisting of nodes and labeled edges (arcs connecting nodes). (Gevarter, 1985)

Semantic Primitives : Basic conceptual units in which concepts, ideas, or events can be represented. (Gevarter, 1985)

Semi-Structured Decisions : Decisions in which some aspects of the problem are structured and others are unstructured. (Turban, 1990)

Sensitivity Analysis : A study of the effect of a change in one or more input variables on a proposed solution. (Turban, 1990)

Sensory System : Any system that monitors the external environment for a computer. (Turban, 1990)

Sequential Processing : The traditional computer processing technique of performing actions one at a time, in a sequence. (Turban, 1990)

S-Expression : A symbolic expression. In LISP, a sequence of zero or more atoms or S-expressions enclosed in parentheses. (Gevarter, 1985)

Simulation : An imitation of reality. (Turban, 1990)

Slot : An element in a frame representation to be filled with designated information about the particular situation. (Gevarter, 1985)

Software : A computer program. (Gevarter, 1985)

Solution Path : A successful path through a search space. (Gevarter, 1985)

Speech Recognition : Recognition by a computer (primarily by pattern matching) of spoken words or sentences. (Gevarter, 1985)

Speech Synthesis : Developing spoken speech from text or other representations. (Gevarter, 1985)

Speech Understanding : Speech perception by a computer. (Gevarter, 1985)

SRI Vision Module : An important object recognition, inspection, orientations, and location research vision system developed at SRI. This system converted the scene into a binary image and extracted the calculated needed vision parameters in real time, as it sequentially scanned the image line by line. (Gevarter, 1985)

State Graph : A graph in which the nodes represent the system state and the connecting arcs represent the operators which can be used to transform the state from which the arcs emanate to the state at which they arrive. (Gevarter, 1985)

Stereotyped Situation : A generic, recurrent situation such as "eating at a restaurant" or "driving to work." (Gevarter, 1985)

Strategic Models : Planning models, usually for the long run, that encompass the corporate strategies for development and growth. (Turban, 1990)

Subgoals : Goals that must be achieved to achieve the original goal. (Gevarter, 1985)

Subplan : A plan to solve a portion of the problem. (Gevarter, 1985)

Subproblems : The set of secondary problems that must be solved to solve the original problem. (Gevarter, 1985)

Syllogism : A deductive argument in logic whose conclusion is supported by two premises. (Gevarter, 1985)

Symbolic : Relating to the substitution of abstract representation (symbols) for concrete objects. (Gevarter, 1985)

Symbolic Concept Acquisition : The Version Space approach evaluates the examples incrementally, and yields descriptions that will not mis-identify any of the examples. Top-Down Induction of Decision Trees (TDIDT) systems examine sets of examples, and yield decision trees which will classify the examples correctly. (Sandman, 1992)

Synchronous Transmission : Transmission of data at timed intervals between terminals and/or computers. (Long, Long, 1993)

Syntax : The order of arrangement (e.g., the grammar) of a language. (Gevarter, 1985)

Synthetic Environment : A simulation that is created using virtual reality technologies. Contains three components - live, constructive, and virtual. The live component is defined as operations with real equipment in the field. The constructive component is defined as war games, models, or other analytical tools. The virtual component is defined as systems and troops in simulators fighting on synthetic environments. (Starr, 1993)

Terminal Node (Leaf Node) : The final node emanating from a branch in a tree or graph representation. (Gevarter, 1985)

Theorem : A proposition, or statement, to be proved based on a given set of premises. (Gevarter, 1985)

- Theorem Proving** : A problem-solving approach in which a hypothesized conclusion (theorem) is validated using deductive logic. (Gevarter, 1985)
- Time Sharing** : A computer environment in which multiple users can use the computer virtually simultaneously via a program that time-allocates the use of computer resources among the users in a near-optimum manner. (Gevarter, 1985)
- Top-Down Approach** : An approach to problem solving that is goal-directed or expectation-guided based on modes or other knowledge. Sometimes referred to as "hypothesize and test." (Gevarter, 1985)
- Top-Down Logic** : A problem-solving approach used in production systems, where production rules are employed to find a solution path by chaining backward from the goal. (Gevarter, 1985)
- Transparent** : A reference to a procedure or activity that occurs automatically. It does not have to be considered in the use or design of a program or an information system. (Long, Long, 1993)
- Tree Structure** : A graph in which one node, the root, has no predecessor node, and all other nodes have exactly one predecessor. For a state-space representation, the tree starts with a root node (representing the initial problem situation). Each of the new states that can be produced from this initial state by application of a single operator is represented by a successor node of the root node. Each successor node branches in a similar way until no further states can be generated or a solution is reached. Operators are represented by the directed arcs from the nodes to their successor nodes. (Gevarter, 1985)
- Truth Maintenance** : A method of keeping track of beliefs (and their justifications) developed during problem solving, so that if contradictions occur, the incorrect beliefs or lines of reasoning, and all conclusions resulting from them, can be retracted. (Gevarter, 1985)
- Truth Value** : One of the two possible values—true or false—associated with a proposition in logic. (Gevarter, 1985)
- Uncertainty** : In the context of expert systems, uncertainty refers to a value that cannot be determined during a consultation. Many expert systems can accommodate uncertainty. That is, they allow the user to indicate if he does not know the answer. (Turban, 1990)
- Uncontrollable Variations** : Factors that affect the result of a decision but are not under the control of the decisionmaker. These can be internal (technology, policies) or external (legal, climate). (Turban, 1990)
- Unfreezing** : The first phase in the treatment of resistance to change, creating an awareness of the need for change. (Turban, 1990)
- Unification** : The name for the procedure for carrying out instantiations. In unification, the attempt is to find substitutions for variables that will make two atoms identical. (Gevarter, 1985)
- Unstructured Decisions** : Complex decisions for which no standard solution exists. (Turban, 1990)

User Interface : The component of a computer system that allows bi-directional communication between the system and the user. (Turban, 1990)

Variable : A quantity or function that may assume any given value or set of values. (Turban, 1990)

Virtual Image : Visual, auditory and tactile stimuli which are transmitted to the senses such that they appear to originate from within a three dimensional space surrounding the user. (Furness, 1992)

Virtual Interface : A system of transducers, signal processors, computer hardware and software that create an interactive medium through which: 1) information is transmitted to the senses in the form of three dimensional virtual images; 2) psychomotor and physiological behavior of the user is monitored and used to manipulate virtual images. (Furness, 1992)

Virtual Reality : The representation of a computer model or database in the form of a system of virtual images which creates an interactive environment which can be experienced and/or manipulated by the user. (Furness, 1992)

Von Neumann Architecture : The current standard computer architecture that used sequential processing. (Gevarter, 1985)

“What If” Analysis : The capability of “asking” the computer what the effect will be of changing some of the input data. (Turban, 1990)

World Knowledge : Knowledge about the world (or domain of interest). (Gevarter, 1985)

World Model : A representation of the current situation. (Gevarter, 1985)

Workplace : A globally accessible database used in expert systems for recording intermediate, partial results of problem solving. (Turban, 1990)

APPENDIX B

HUMAN SITUATION ASSESSMENT MODELS AND INFORMATION PROCESSING BIASES¹

Economic Rationality : Maximum goal achievement with respect to technical production of a single product, subject to a production cost constraint, is the typical desired end of economic rationality. It seeks to maximize the overall worth, in an economic sense, of a number of investments. This is possible if desired goals are well defined and measurable, the techniques employed to attain these goals are not limited in scope or hindered in application, supply and demand operates in a stable manner, and the interrelationships of supply and demand are known and available to all — in other words, if the requirements for a “perfectly competitive economy” are satisfied. Using this model of rationality, it is possible to maximize goal achievement should there be any constraints placed on the above requirements. Some goals can typically be achieved and this results in enhanced economic progress. Achievements of some goals become the means toward the achievement of other societally desirable goals. This process continues, and the continuation of economic progress itself becomes the top-level goal to be achieved. From an economic rationality perspective, those items of information not providing a basis for increasing the profit goals of an organization are to be avoided.

Technical Rationality : The activities of an individual are determined in such a way as to maximize the return, or benefit, to the individual from the investment cost of that activity. Most traditional engineering and organizational analysis has presumed, at least implicitly, technical rationality. Systems are presumed to be designed such as to achieve “optimal attainment” of objectives. The presence of multidimensional and noncommensurate objectives will frequently prevent this sort of optimization from being easily accomplished. The need for coordination and communication among people in modern decentralized organizations also makes attaining technical rationality difficult. Implementation of technical rationality results in what is called the *rational actor Model*. Most formal decision analytic efforts are based on the technically rational actor model. In this model, the decisionmaker becomes aware of a problem, studies it, carefully weighs alternative means to a solution, and makes a choice or decision based on an objective set of values. This is a normative substantive model. There may be any number of descriptive process realities that make prescriptive realization infeasible. In rational planning or decisionmaking, the following steps are typically performed:

¹The following list and discussion is drawn from Sage, 1991, pp. 235-252. The reader is directed to various articles published by Kahneman and Tversky, principally “Judgement under Uncertainty: Heuristics and Biases” for additional information.

1. The decisionmaker is confronted with an issue that can be meaningfully isolated from other issues.
2. Objectives, which will result in need satisfaction, are identified.
3. Possible alternative activities to resolve needs are identified.
4. The impacts of action alternatives are determined.
5. The utility of each alternative is evaluated in terms of its impacts on needs.
6. The utilities of all alternatives are compared and the policy or activity with the highest utility is selected for action implementation.

The decisionmaker becomes aware of a problem, structures the problem space, gathers information, identifies the impacts of alternatives, and implements the best alternative based on a set of values. The effects of alternatives that are proposed for implementation, including the effects they have on the environment in which they are to be utilized, are determined in detail using the technologies of systems engineering. Cost-benefit analysis are determined, risk-assessment is performed, statistics are used, computer models are constructed, and other systems science and operations research methods are employed in order to ascertain the effects and results of a particular alternative that is being considered for implementation. Since a complete identification of all needs, alterables, objectives, and so on, is not usually possible, one cannot be completely rational in the purest sense.

Satisficing Or Bounded Rationality : Decisions are implemented based on a minimum set of requirements to provide a degree of acceptable achievement over the short term. The decisionmaker does not attempt to extremize an objective function, but rather attempts to achieve some aspiration level. The aspiration level may possibly change due to the difficulty in searching for a solution. It may be lowered in this case, or raised if the goal or aspiration level is too easily achieved.

This model makes use of the observation that unaided decisionmakers may not be able to make complete substantive use of the economic and technically rational actor model possible. In these situations, the concepts of bounded rationality and satisficing represent much more realistic substantive models of actual decision rules and practices. According to the satisficing or bounded rationality model, the decisionmaker looks for a course of action that is basically good enough to meet a minimum set of requirements. The goal, from an organizational perspective, is "do not shake the system" or "play it safe," by making decisions primarily on the basis of short-term acceptability rather than seeking a long-term optimum. It has been suggested that decisionmakers compensate for their limited abilities by constructing a simplified representation of the problem and then behave rationally within the constraints imposed by this simplified model. We may satisfice by finding either optimum solutions in a simplified world or satisfactory solutions in a more realistic world.

Satisficing is actually searching for a "good enough" choice. The threshold for satisfaction, or aspiration level, may change according to the ease or difficulty of search. If many alternatives can be found, the conclusion is reached that the aspiration level is too low and needs to be increased. The converse is true if no satisfactory alternatives can be found. This may lead to a unique solution through iteration. The principle of bounded rationality and the resulting satisficing model suggest the simple heuristics may well be adequate for complex problem-solving situations.

Social Rationality : Society functions as a unit seeking betterment for itself. All its energy is directed toward the realization of this goal. The social system is cohesive in that all its activities reinforce achievement of the desired goal. Recent decisions are related to those of the past and are projected into the future. While these actions and decisions are usually not efficient and sometimes not even effective, the cohesiveness of society provides continuity for the system. The roles and structure of society are reinforced from previous results, both good and bad, lending credence to the fact that a social system is rather intractable. It maintains a conservative appearance and avoids risk. That it ought to be adaptive to change perhaps can be shown by sudden changes in the morality or consciousness of the members of the society through a violent opposition to the status quo.

Political Rationality : The decisionmaking structure is assumed to be influenced by embedded beliefs, values, and interpersonal relationships, the interaction of which define roles under which actions and decisions are based. The three characteristics of this rationality are that all actors remain independent regardless of the pressures to be dependent on one another, the work load is distributed among all members so as to balance and moderate actions of the group, and future decisions are chosen in such a way that the impacts of these decisions will act to bind the group further together and increase participation.

Legal Rationality : A system exhibiting this form of rationality operates on the basis of rules that are complex, consistent, precise, and detailed. As a result, no ambiguous conflict can occur. It is effective in preventing disputes even though the rules of this system apply differently, to some extent, to each person. The prevention of disputes is accomplished through a "legal" framework that provides a means for settlement of disputes that do result and that sets precedents to guide members of society.

Substantive Rationality : This is the classic, input-output, or means-ends rationality of economics. This form of rationality is outcome-oriented in that behavior is considered acceptable when given goals are achieved. Given a set of goals, rational behavior is determined by the characteristics of the environment in which it takes place. For instance, use of the methods of optimum systems control will result in a system that achieves a goal while satisfying a set of constraint equations that governs the behavior of the physical system concerned.

Procedural Rationality : This is the prevalent rationality of descriptive decisionmaking in which any decisionmaking process must necessarily correspond to the capabilities of the user. It must allow a person to make use of those knowledge components that make maximum use of that person's abilities and minimize use of those knowledge components concerning areas in which the decisionmaker is not able to perform effectively. Behavior is rational, in a procedural sense, when a person effectively uses existing cognitive powers to choose actions in order to alleviate some issue. It is the process of selecting procedures for resolution of issues that is the basis for and the justification of rationality, rather than the outcome of the decisions. Procedural rationality is the method of searching for information for solutions to problems.

Bureaucratic Politics, Incrementalism, Or "Muddling-Through" Rationality : Bold changes to existing policies are avoided and decisions are based on a rather limited set of alternatives which basically are minor perturbations of existing policies. Long-range side effects are not dealt with, but rather are left to future decisionmakers who ameliorate these side effects with other incremental policies. This model attempts to characterize individual and organizational behavior. After problems arise that require a change of policy, policy makers typically consider only a narrow range of alternatives differing a small degree from the existing policy. One alternative is selected and tried, with unforeseen consequences left to be discovered and treated by subsequent incremental policies. This is a realistic process-oriented descriptive model of judgment and choice.

This model recognizes the following limitations to analysis: It is fallible, never rising to infallibility, and can be poorly informed, superficial, biased, or mendacious. It cannot wholly resolve conflicts of value and interest. Sustained analysis may be too slow and too costly compared with realistic needs. The main features of this model are: ends and means are viewed as not distinct. Consequently, means-ends analysis is viewed as often inappropriate. Identification of values and goals is not distinct from the analysis of alternative actions. Rather, the two processes are confounded. The test for a good policy is typically that various decisionmakers, or analysts, agree on a policy as suitable without necessarily agreeing that is the most appropriate means to an end. Analysis is drastically limited, significant policy options are neglected, and important outcomes are not considered. By proceeding incrementally and comparing the results of each new policy with the old, decisionmakers reduce or eliminate reliance on theory.

Organizational Processes Rationality : In the purest form of the organization, everyone in it is aware of how it functions, because these functions are spelled out in a well-communicated set of standard operating procedures. Decision to be made are structured around, and evaluated in terms of, these procedures. Information needs are determined through discovery of how these standard operating policies or rules affected previous problems. Plans and decisions are the result of interpretation of standard operating procedures. Improvements are obtained by careful identifications of existing standard operating procedures and associated organizational structures and determination of improvements in these procedures and structures. The organizational process model functions by relying on standard operating procedures, which constitute the memory or intelligence bank of the organization. Only if the standard operating procedures fail will the organization attempt to develop new standard procedures.

The organizational process model may be viewed as an extension of the concept of bounded rationality to organizations. There are four main concepts of the behavioral theory of the firm that are suggested as descriptive models of actual choice-making in organizations:

1. *Quasi-resolution of Conflict.* Decisionmakers avoid conflicts arising from noncommensurate and conflicting goals. Major problems are disaggregated and each subproblem is attacked locally by a department. An acceptable conflict resolution between the efforts of different departments is reached through sequential attention to departmental goals and through the formulation of coalitions which seek power and status. When resources are scarce and there must then be unsatisfied objectives, decisions concerning allocations will be met largely on political grounds.

2. *Uncertainty avoidance* is achieved by reacting to external feedback, by emphasizing short-term choices, and by advocating negotiated futures. Typically, there will be uncertainties about the future, including those associated with future impacts of alternatives and future preferences. Generally, deficient information-processing heuristics and cognitive biases are used to avoid uncertainties.

3. *Problem search* is stimulated by encountering issues, and not before issues are surfaced. A form of "satisficing" is used as a decision rule. Search in the neighborhood of the status quo only is attempted and only incremental solutions are considered.

4. *Organizational Learning*. Organizations adapt on the basis of experience. They often pay considerable attention to one part of their environment at the expense of another.

The organizational process model may be viewed as suggesting that decisions at time t may be forecasted with almost complete certainty, from knowledge of decisions at time $t - T$ where T is the planning or forecasting period. Standard operating procedures or "programs," and education motivation and experience or "programming" of management are the critical determinants of behavior for the organizational process model.

Garbage Can Rationality : An organization is also a mechanism for problem solving and decisionmaking. When the realities of ambiguity are associated with organizational problem solving and decisionmaking, the result is what is termed a *garbage can model* of organizational choice. In this model, there are five fundamental elements:

- Issues or problems
- Organizational structure
- Participants, actors, or agents
- Choice opportunities and actions
- Solutions or products of the choice process.

The problems, solutions, and choice opportunities are assumed to be quasi-independent, exogenous "*streams*" that are *linked* in a fashion that is determined by organizational structure constraints. There are several of these. The most important are *access structure*, or the access of problems to choice opportunities, *decision structure*, or the access of choice opportunities to solutions, and *energy structure*, which evolves in a dynamic fashion in terms of the number of problems or solutions that are linked to choice opportunities at a particular time.

The participants in the process can also be regarded as variables, since they "come and go" over time, and devote varying amounts of time and energy to problems, solutions, and choice opportunities owing to other competing demands on their time. This model views organizational decisionmaking as resulting from four variables: problems, solutions, choice opportunities, and people.

Decisions result from the interaction of solutions looking for problems, problems looking for solutions, decision opportunities, and participants in the problem-solving process. The model allows for these variables being selected more or less at random from a garbage can. The interaction of these variables provides the opportunity for decisionmaking. Generally, these interactions are not controlled. Rather, they occur in an almost random fashion owing to the vexing equivocality associated with problematic preferences, unclear procedures, and fluid participants. The major reason for the garbage can approach is the chronic ambiguity and considerable equivocality that is present in the environment.

In a "garbage can" environment, decisions generally occur through rational problem solving, through ignoring the problem until it goes away or resolves itself, or through having the problem solved, inadvertently, by having another related problem solved.

Three areas of equivocality are generally present in a garbage can environment:

1. *Problematic preferences* — in that different decisionmaking units have different objectives, and these generally evolve over time in an imprecise and unpredictable manner.

2. *Unclear procedures for making decisions* — in that responsibility and authority are usually separated and fragmented.

3. *Fluid decision participation* — in that the members of the decision-making units change over time, in an often unpredictable manner.

In the garbage can model, the problems, solutions, and choice opportunities are mixed together in "garbage cans." The division of human effort among problems, solutions, and choices is fuzzy and not fixed in any highly organized way. Problems, solutions, and choice opportunities may not coalesce in the right way at the right time so as to lead to a "rational" solution to the problem.

One of the most potentially useful features of the garbage can model is that it is a definitive approach for relating social structure to cognitive structure. It is a potentially serviceable organizational model that can cope with such potential crisis situations as breakdown in organizational communications.

Anchoring And Adjustment : Often a person finds that difficulty in problem solving is due not to the lack of data and information, but rather to the existence of excess data and information. In such situations, the person often resorts to heuristics which may reduce the mental efforts required to arrive at a solution. In using the anchoring and adjustment heuristic when confronted with a large amount of data, the person selects a particular datum as a starting point, or anchor, and then adjusts that value improperly in order to incorporate the rest of the data such as to result in flawed information.

Availability : The decisionmaker uses only easily available information and ignores not easily available sources of significant information. An event is believed to occur frequently — that is, with high probability — if it is easy to recall similar events.

Base Rate : The likelihood of occurrence of two events is commonly compared by contrasting the number of times the two events occur and ignoring the rate of occurrence of each event. This bias often occurs when the decisionmaker has concrete experience with one event but only statistical or abstract information on the other. In general, abstract information will be ignored at the expense of concrete information. A base rate determined primarily from concrete information may be called a causal base rate, whereas that determined from abstract information is an incidental base rate. When information updates occur, this individuating information frequently is given much more weight than it deserves. It is much easier for individuating information to override incidental base rates than causal base rates.

Confirmation Bias : People are more prone to utilize information that is likely to validate currently held beliefs than information that might disconfirm or falsify these beliefs.

Conservatism : The failure to revise estimates as much as they should be revised, based on receipt of new significant information, is known as conservatism. This is related to data saturation and regression effects biases.

Data Presentation Context : The impact of summarized data, for example, may be much greater than that of the same data presented in detail, nonsummarized form. In addition, different scales may be used to change the impact of the same data considerably.

Data Saturation : people often reach premature conclusions on the basis of too small a sample of information while ignoring the rest of the data that is received later on, or stopping acquisition of data prematurely.

Desire For Self-Fulfilling Prophecies : the decisionmaker values a certain outcome, interpretation, or conclusion and acquires and analyzes only information that supports this conclusion. This is another form of selective perception.

Ease Of Recall : Data that can easily be recalled or assessed will affect perception of the likelihood of similar events occurring again. People typically weigh easily recalled data more in decisionmaking than those data that cannot easily be recalled.

Expectations : people often remember and attach higher validity to information that confirms their previously held beliefs and expectations than they do to disconfirming information. Thus, the presence of large amounts of information make it easier for one to selectively ignore disconfirming information such as to reach any conclusion and thereby prove anything that one desires.

Fact-Value Confusion : Strongly held values may frequently be regarded and presented as facts. That type of information is sought that confirms or lends credibility to one's views and values. Information contradicting one's views or values is ignored. This is related to wishful thinking in that both are forms of selective perception.

Fundamental Attribution Error (Success/Failure Error) : The decisionmaker associates success with personal inherent ability and associates failure with poor luck in chance events. This is related to availability and representativeness.

Gamblers' Fallacy : The decisionmaker falsely assumes that unexpected occurrence of a "run" of some events enhances the probability of occurrence of an event that has not occurred.

Habit : Familiarity with a particular rule for solving a problem may result in reutilization of the same procedure and selection of the same alternative when confronted with a similar type of problem and similar information. We choose an alternative because it has previously been acceptable for a perceived similar purpose, or because of superstition.

Hindsight : People are often unable to think objectively if they receive information that an outcome has occurred and they are told to ignore this information.

Illusion Of Control : A good outcome in a chance situation may well have resulted from a poor decision. The decisionmaker may assume a feeling of control over events that is not reasonable.

Illusion Of Correlation : A mistaken belief that two events covary when they do not covary is known as the illusion of correlation.

Law Of Small Numbers : People are insufficiently sensitive to the available quantity and quality of evidence. They commonly express greater confidence in predictions based on small samples of data with nondisconfirming evidence than in much larger samples with minor disconfirming evidence. Sample size and reliability frequently have little influence on confidence.

Order Effects : The order in which information is presented affects information retention in memory. Typically, the first piece of information presented (primacy effect) and the last presented (recency effect) assume undue importance in the mind of the decisionmaker.

Outcome-Irrelevant Learning System : Use of an inferior information processing or decision rule can lead to poor results, and the decisionmaker can believe that these are good because of inability to evaluate the impacts of the choices not selected and the hypotheses not tested.

Overconfidence : People generally ascribe more credibility to data than is warranted and hence overestimate the probability of success merely owing to the presence of an abundance of data. The greater the amount of data, the more confident the person is in the accuracy of the data.

Redundancy : The more redundancy in the data, the more confidence people often have in their predictions, although this overconfidence is usually unwarranted.

Reference Effect : People normally perceive and evaluate stimuli in accordance with their present and past experiential level for the stimuli. They sense a reference level in accordance with past experience. Therefore, reactions to stimuli are interpreted favorably or unfavorably in accordance with previous expectations and experiences. A reference point defines an operating point in the space of outcomes. Changes in perceptions, due to changes in the reference point, are called reference effects. These changes may not be based on proper, statistically relevant computations.

Regression Effect : The largest observed values of observations are used without regressing toward the mean to consider the effects of noisy measurements. In effect, this ignores uncertainties.

Representativeness : When making inference from data, too much weight is given to results of small samples. As sample size is increased, the results of small samples are taken to be representative of the larger population. The "laws" of representativeness differ considerably from the laws of probability and violations of the conjunction rule, $P(A|B) < P(A)$, are often observed.

Selective Perceptions : people often seek only information that confirms their views and values. They disregard or ignore disconfirming evidence. Issues are structured on the basis of personal experience and wishful thinking. There are many illustrations of selective perception. One is "reading between the lines" such as, for example, to deny antecedent statements and, as a consequence, accept "if you don't promote me, I won't perform well" as following inferentially from "I will perform well if you promote me."

Spurious Cues : Frequently, cues appear only by occurrence of a low-probability event, but they are accepted by the decisionmaker as commonly occurring.

Substitution Of Correlation For Causation : often, we assume that because two events are correlated, there must also be some causative relation between them. Causation must imply correlation. However, correlation does not infer any necessary causative relationships.

Wishful Thinking : The preference of the decisionmaker for particular outcomes and particular decisions can lead the decisionmaker to choose an alternative that the decisionmaker would like to have associated with a desirable outcome. This implies a confounding of facts and values and is a form of selective perception.

REFERENCES

- BARRETT, C.L., and M.L. DONNELL, "Real Time Expert Advisory Systems: Considerations and Imperatives," *Information and Decision Technologies*, Vol. 16, 1990, pp. 15-25.
- BLACKMAN, S.S., "Theoretical Approaches to Data Association and Fusion," *Proceedings: Sensor Fusion*, Bellingham: The International Society for Optical Engineering, 1988, pp. 50-55.
- BRICKEN, MEREDITH, "Virtual Worlds: No Interface to Design," *Cyberspace: First Steps*, edited by M. Benedikt, Cambridge: The MIT Press, 1991, pp. 363-382.
- BYRNE, C.D., W.L. LAKIN, and J.A.H. MILES, "Intelligent Data Fusion for Naval Command and Control," *C3 and Management Information Systems*, London, IEE, 1987.
- "C4I For the Warrior Objective Concept: Coordination Draft," C4 Architecture & Integration Division (J6I), J-6, The Joint Staff, The Pentagon, Washington, D.C., 4 September 1992.
- COMPARATO, V.G., "Fusion — The Key to Tactical Mission Success," *Proceedings: Sensor Fusion*, Bellingham: The International Society for Optical Engineering, 1988, pp. 2-7.
- "Copernicus Architecture," Copernicus Project Team, Director, Space and Electronic Warfare (OP-094), Office of the Chief of Naval Operations, Washington, D.C., 1992.
- DANIELS, J., "Artificial Intelligence: A Brief Tutorial," *Artificial Intelligence and National Defense: Applications to C3I and Beyond*, Washington, D.C.: AFCEA International Press, 1987, pp. 3-12.
- DOS SANTOS, B.L., and V.S. MOOKERJEE, "An Economic Approach to the Development of Inductive Expert Systems," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 36-46.
- FITZGERALD, M., "Russia's New Military Doctrine," *Naval War College Review*, Volume XLVI, Number 2, Sequence 342, Spring 1993, pp. 24-44.
- FURNESS, T. A., III, Class Notes and Selected Charts, Human Interface Technology Lab, University of Washington, Seattle, WA, 1992.
- GEVARTER, W. B., *Intelligent Machines: An Introductory Perspective of Artificial Intelligence and Robotics*, Englewood Cliffs: Prentice-Hall, INC., 1985.

- GLASS, A.L., K.J. HOLYOAK, and J.L. SANTA, *Cognition*, Reading: Addison-Wesley Publishing Company, 1979.
- HANDEL, M.I., Editor, *Intelligence and Military Operations*, London: Frank Cass and Company, Ltd., 1990.
- HARRIS, S.D., J. OWENS, C. BARRETT, M. PARISI, and D. BECKER, "Sensor Fusion and Situation Assessment: A Perspective," Washington D.C., Naval Air Systems Command, 1991.
- HARRISON, P.R., J.M. OWENS, P.A. RATCLIFFE, and S.D. HARRIS, "The Validation of Embedded Knowledge-Based Systems," Washington D.C., Naval Air Systems Command, May 1992.
- HARRISON, P.R., P.A. RATCLIFFE, J.M. OWENS, and S.D. HARRIS, "The Validation of Embedded Knowledge-Based Systems," *Proceedings of the Twenty-Second Annual Modeling and Simulation Conference*, University of Pittsburgh, Pittsburgh, PA, 2-3 May 1991.
- HARRISON, P.A., P.R. HARRISON, M.A. PARISI, and S.D. HARRIS, "Intelligent Real-time Sensor Control," Naval Air Systems Command, Washington D.C., March 1991.
- HOGARTH, R.M., *Judgment and Choice*, 2nd Edition, Chichester: John Wiley & Sons, 1987.
- JACKSON, PETER, *Introduction to Expert Systems*, 2nd Edition, Wokingham: Addison-Wesley Publishing Company, 1990, pp. 4-5.
- KAHNEMAN, D. and A. TVERSKY, "On the Study of Statistical Intuitions," *Judgment Under Uncertainty: Heuristics and Biases*, edited by D. Kahneman, P. Slovic, and A. Tversky, Cambridge: Cambridge University Press, 1982, pp. 493-508.
- KAHNEMAN, D. and A. TVERSKY, "Intuitive Prediction: Biases and Corrective Procedures," *Judgment Under Uncertainty: Heuristics and Biases*, edited by D. Kahneman, P. Slovic, and A. Tversky, Cambridge: Cambridge University Press, 1982, pp. 414-421.
- LAKIN, W.L., and J.A.H. MILES, "IKBS in Multi-Sensor Data Fusion," *International Conference on C3: Advances in Command, Control and Communication Systems - Theory and Applications*, London: IEE, 1985, pp. 234-235.
- LOESCHER, M.S., LCDR, USN, *Space and Electronic Warfare: A Navy Policy Paper on a New Warfare Area*, Space and Electronic Warfare, Office of the Chief of Naval Operations, Room 5B740, the Pentagon, Washington, D.C., 20350-2000, April 1992.
- LONG, L. and N. LONG, *Computers*, 3rd Edition, Englewood Cliffs, Prentice-Hall, 1993.

- LUO, R.C. and M.G. KAY, "Multisensor Integration and Fusion: Issues and Approaches," *Proceedings: Sensor Fusion*, Bellingham: The International Society for Optical Engineering, 1988, pp. 42-49.
- NAYLOR, R.T., "Battlefield Data Fusion," *C3 and Management Information Systems*, London: IEE, 1987, p. 95.
- NOVAK, M., "Liquid Architectures in Cyberspace," *Cyberspace: First Steps*, edited by M. Benedikt, Cambridge: The MIT Press, 1991.
- ORR, G.E., *Combat Operations C3I: Fundamentals and Interactions*, Maxwell Air Force Base: Air University Press, 1983.
- RHEINGOLD, H., *Virtual Reality*, New York: Touchstone, 1991.
- SAGE, A.P., *Decision Support Systems Engineering*, New York: John Wiley & Sons, Inc., 1991.
- SANDERS, M.S., and E. J. MCCORMICK, *Human Factors in Engineering and Design*, 6th Edition, New York: McGraw-Hill Book Company, 1987.
- SANDMAN, THOMAS E., "Induction Support for KBDSS Development: A Proposed System Design," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 4-13.
- SHORTLIFFE, E.H., "Medical Consultation Systems," M.E. Sime and M.J. Coombs, Editors, *Designing for Human-Computer Communication*, London: Academic Press, Inc., 1983, pp. 209-238.
- SMITH, C.L., and A.P. SAGE, "Situation Assessment in Command and Control," *Information Technology for Command and Control*, edited by S.J. Andriole and S.M. Halpin, New York: IEEE Press, 1991, pp. 449-465.
- STARR, S. H., "Synthetic Environments and C2," Information Briefing to Students of the Joint Command, Control, and Communications curriculum at the Naval Postgraduate School, Monterey, CA, 18 February, 1993.
- "The Ghost in the Machine," *The Economist*, Volume 327, Number 7810, May 8th-14th, 1993, p. 92.
- TURBAN, E., *Decision Support and Expert Systems: Management Support Systems*, 2nd Edition, New York: Macmillan Publishing Company, 1990, pp. 669-670.
- WALDEN, P., "Rule-Based Expert Systems in Strategic market Management," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 111-121.
- WATKINS, P.R., et al., "AI Integration for Enhanced Decision Support," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III:

Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 133-144.

WIDMEYER, G.R., "Executive Support in an Open Loop Control Environment,"
Proceedings of the Hawaii International Conference on System Sciences, 1992,
Volume III: Information Systems: Decision Support and Knowledge-Based
Systems, IEEE. pp. 166-175.

WOOLSEY, R.B., "Application of Expert System Technology to an Information Fusion
System," *C3 and Management Information Systems*, London: IEE, 1987, p. 85.

YAZICI, H., K. MUTHUSWAMY, and J. VILA, "An Expert System Approach for
Interface Management in Decision Support Systems," *Proceedings of the Hawaii*
International Conference on System Sciences, 1992, Volume III: Information
Systems: Decision Support and Knowledge-Based Systems, IEEE, pp. 101-110.

BIBLIOGRAPHY

- ABOUTALIB, A.O., "Embedded Knowledge-Based System for Automatic Target Recognition," *Proceedings: Sensor Fusion III*, Bellingham: The International Society for Optical Engineering, 1990, pp. 205-219.
- ALTES, R.A., *Adaptive Sensor Fusion with Optimum Multilevel Quantization*, Chirp CORP, 1988 [DTIC AD-B123 535].
- ANDRIOLE, S. J., et al., *Decision Aids for Naval Anti-Air Warfare (AAW)*, Orlando: Naval Training Systems Command, 1991.
- ANDRIOLE, S. J., Editor, *Artificial Intelligence and National Defense: Applications to C3I and Beyond*, Washington, D.C.: AFCEA International Press, 1987.
- APPLIED PHYSICS LABORATORY, Johns Hopkins University, *Battle Group Anti-Air Warfare Coordination (BGAAWC) Cooperative Engagement system*, August 1987.
- BARAGHIMIAN, G.A., and A. KLINGER, "Preference Voting for Sensor Fusion," *Proceedings: Sensor Fusion III*, Bellingham: The International Society for Optical Engineering, 1990, pp. 46-57.
- BARRETT, C.L., and M.L. DONNELL, "Real Time Expert Advisory Systems: Considerations and Imperatives," *Information and Decision Technologies*, Vol. 16, 1990, pp. 15-25.
- BEAM, W.R., *Command, Control, and Communications Systems Engineering*, New York: McGraw-Hill Publishing Company, 1989.
- BENEDIKT, M., Editor, *Cyberspace: First Steps*, Cambridge: The MIT Press, 1991.
- BETTS, R. K., *Surprise Attack*, Washington D.C.: The Brookings Institute, 1982.
- BLACKMAN, S.S., "Theoretical Approaches to Data Association and Fusion," *Proceedings: Sensor Fusion*, Bellingham: The International Society for Optical Engineering, 1988, pp. 50-55.
- BRANDSTADT, J., *Spatial and Temporal Registration of Dissimilar Sensors*, Integrated Sensors INC., 1991.
- BRAND, S., *The Media Lab: Inventing the Future at MIT*, New York: Penguin Books, 1987.
- BRICKEN, MEREDITH, "Virtual Worlds: No Interface to Design," *Cyberspace: First Steps*, edited by M. Benedikt, Cambridge: The MIT Press, 1991, pp. 363-382.

- BRIGGS, R.O., et al., "Is the Pen Mightier Than the Keyboard?", *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 201-210.
- BROWN, D.E., et al., "Neural Network Implementations of Data Association Algorithms for Sensor Fusion," *Proceedings: Sensor Fusion II*, Bellingham: The International Society for Optical Engineering, 1989, pp. 126-135.
- BROWN, D.E., et al., "A Simulation-Based Test Bed for Data Association Algorithms," *Proceedings: Sensor Fusion III*, Bellingham: The International Society for Optical Engineering, 1990, pp. 58-68.
- BULLOCK, T.E., and E.J. BOUDREAUX, "Sensor Fusion in a Nonlinear Dynamical System," *Proceedings: Sensor Fusion II*, Bellingham: The International Society for Optical Engineering, 1989, pp. 109-116.
- BYRNE, C.D., W.L. LAKIN, and J.A.H. MILES, "Intelligent Data Fusion for Naval Command and Control," *C3 and Management Information Systems*, London, IEE, 1987.
- "C4I FOR THE WARRIOR," An information paper signed by GEN Colin Powell, USA, CJCS, 12 June, 1992.
- "C4I For the Warrior Objective Concept: Coordination Draft," C4 Architecture & Integration Division (J6I), J-6, The Joint Staff, The Pentagon, Washington, D.C., 4 September 1992.
- CAIN, M.P., et al., "Object Classification Using Multispectral Sensor Data Fusion," *Proceedings: Sensor Fusion II*, Bellingham: The International Society for Optical Engineering, 1989, pp. 53-60.
- CARLEY, "Designing Organizational Structure to Cope With Communication Breakdowns: A Simulation Model," 1990, CC4001/2 Class Notes.
- CASTELAZ, P.F., *Neural Network Data Fusion (NDF) Research*, Hughes Aircraft CO., 1990 [DTIC - AD-B155 720].
- CASTELAZ, P.F., *Neural Network Data Fusion (NDF) Research*, Hughes Aircraft CO., 1989 [DTIC - AD-B136 964].
- CHANDRA, D.V.S., "Multisensor Seeker for Medium Range Air-to-Air Missiles," *Proceedings: Sensor Fusion III*, Bellingham: The International Society for Optical Engineering, 1990, pp. 180-186.
- CHAUDHURI, S.P., et al., "Artificial Intelligence Applications to Command, Control, and Communication Systems/Subsystems," *Proceedings: Sensor Fusion II*, Bellingham: The International Society for Optical Engineering, 1989, pp. 85-96.

- CHAUDHURI, S., et al., "Multisensor Data Fusion for Mine Detection," *Proceedings: Sensor Fusion III*, Bellingham: The International Society for Optical Engineering, 1990, pp. 187-204.
- CHEN, S., "Adaptive Control of Multisensor Systems," *Proceedings: Sensor Fusion*, Bellingham: The International Society for Optical Engineering, 1988, pp. 98-102.
- CHI, R.T.H., et al., "A Framework For Distributed Decision Support Systems," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 517-528.
- CLARY, JAMES W., et al., *Headquarters Design Guidelines*, Burlington: AlphaTech, Inc., 1991.
- COAKLEY, THOMAS P., *Command and Control for War and Peace*, Washington D.C.: National Defense University Press, 1991.
- COHEN & GOOCH, *Military Misfortunes: The Anatomy of Failure in War*, 1990, CC4001/2 Class Notes.
- COMPARATO, V.G., "Fusion — The Key to Tactical Mission Success," *Proceedings: Sensor Fusion*, Bellingham: The International Society for Optical Engineering, 1988, pp. 2-7.
- "Copernicus Architecture," Copernicus Project Team, Director, Space and Electronic Warfare (OP-094), Office of the Chief of Naval Operations, Washington, D.C., 1992.
- "Copernicus Functional Description Document (FDD)," NCCOSC RDT&E Division (NRaD), Code 405, San Diego, CA, 06 August 1992.
- COPERNICUS PROJECT OFFICE, *The Copernicus Architecture, Phase I: Requirements Definition*, August 1991, OP-094, Director, Space and Electronic Warfare, Office of the Chief of Naval Operations, Washington, D.C., 20350-2000.
- Côté, V. and R. ST-DENIS, "Bridging the Gap Between CASE Tools and Project Management Through a Decision Support System Based on Metrics," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 300-309.
- "DATA SECURITY," *IEEE Spectrum*, August 1992, Volume 29, Number 8, pp. 18-45.
- DANIELS, J., "Artificial Intelligence: A Brief Tutorial," *Artificial Intelligence and National Defense: Applications to C3I and Beyond*, Washington, D.C.: AFCEA International Press, 1987, pp. 3-12.
- DASARATHY, B.V., "Paradigms for Information Processing in Multisensor Environments," *Proceedings: Sensor Fusion III*, Bellingham: The International Society for Optical Engineering, 1990, pp. 69-80.

- DUETSCHMAN, A. "Bill Gates' Next Challenge," *Fortune*, Vol. 126, No. 14, December 28, 1992, pp. 30-42.
- DIXON, N.F., *On The Psychology of Military Incompetence*, London: Futura Macdonald & Co., 1976.
- DOS SANTOS, B.L., and V.S. MOOKERJEE, "An Economic Approach to the Development of Inductive Expert Systems," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 36-46.
- DUNBAR, SHERRY L., *Computer Human Interface (CHI) Design Guidelines*, Sunnyvale: Lockheed Missiles and Space Company, Inc., 1990.
- DYNETICS, INC., *Integrated Multisensor Processing Analysis*, 1990.
- FERGUSON, EUGENE S., *Engineering and the Mind's Eye*, Cambridge: MIT PRESS, 1992.
- FERNANDEZ, M., et al., "The Procrustes Algorithm for Multisensor Track Fusion," *Proceedings: Sensor Fusion III*, Bellingham: The International Society for Optical Engineering, 1990, pp. 25-44.
- FIELDING, M.R., *Artificial Intelligence Applications for Sensor Data Fusion*, Perceptronics INC., 1988.
- FITGERALD, M., "Russia's New Military Doctrine," *Naval War College Review*, Volume XLVI, Number 2, Sequence 342, Spring 1993, pp. 24-44.
- FURNESS, T. A., III, Class Notes and Selected Charts, Human Interface Technology Lab, University of Washington, Seattle, WA, 1992.
- GAINES, B. R. and M.L.G. SHAW, M.L.G., "Dialog Engineering", *Designing for Human-Computer Communication*, NEW YORK: Academic Press, 1983.
- GARCIA, H.C., et al., "A Semantics-based Methodology for Integrated Computer-Aided Distributed Database Design," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 288-299.
- GERLACH, J., et al., "Computer-Guided Training: How to Make it Work," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 211-218.
- GEVARTER, W. B., *Intelligent Machines: An Introductory Perspective of Artificial Intelligence and Robotics*, Englewood Cliffs: Prentice-Hall, INC., 1985.
- GILBERT, "How Mental Systems Believe," OA3401 Class Notes, 1991.

- GILHOOLY, K.J., editor, *Human and Machine Problem Solving*, New York: Plenum Press, 1989.
- GLASS, A.L., K.J. HOLYOAK, and J.L. SANTA, *Cognition*, Reading: Addison-Wesley Publishing Company, 1979.
- HALPIN, S.M. and MOSES, F.L., "Improving Human Performance Through the Application of Intelligent Systems," *Artificial Intelligence and National Defense: Applications to C3I and Beyond*, Washington, D.C.: AFCEA International Press, 1987, pp. 99-109.
- HANDEL, M.I., *War, Strategy, and Intelligence*, London: Frank Cass and Company, Ltd., 1989.
- HANDEL, M.I., Editor, *Intelligence and Military Operations*, London: Frank Cass and Company, Ltd., 1990.
- HARNEY, R. C., Editor, *Proceedings: Sensor Fusion III*, Bellingham: The International Society for Optical Engineering, 1990.
- HARNEY, R.C., "Practical Issues in Multisensor Target Recognition," *Proceedings: Sensor Fusion III*, Bellingham: The International Society for Optical Engineering, 1990, pp. 105-114.
- HARRIS, C.J., Chairman, *International Conference on Advances in Command, Control and Communication Systems: Theory and Applications*, London: Institution of Electrical Engineers, 1985.
- HARRIS, C.J., Chairman, *Second International Conference on Command, Control, Communications and Management Information Systems*, London: Institution of Electrical Engineers, 1987.
- HARRIS, S.D., J. OWENS, C. BARRETT, M. PARISI, and D. BECKER, "Sensor Fusion and Situation Assessment: A Perspective," Washington D.C., Naval Air Systems Command, 1991.
- HARRIS, S.D., and J.M. OWENS, "Some Critical Factors that Limit the Effectiveness of Machine Intelligence Technology in Military Systems Applications," *Journal of Computer-Based Information*, Spring 1986, Vol. 13, No. 2, pp. 30-34.
- HARRISON, P.R., J.M. OWENS, P.A. RATCLIFFE, and S.D. HARRIS, "The Validation of Embedded Knowledge-Based Systems," Washington D.C., Naval Air Systems Command, May 1992.
- HARRISON, P.R., P.A. RATCLIFFE, J.M. OWENS, and S.D. HARRIS, "The Validation of Embedded Knowledge-Based Systems," *Proceedings of the Twenty-Second Annual Modeling and Simulation Conference*, University of Pittsburgh, Pittsburgh, PA, 2-3 May 1991.

- HARRISON, P.A., P.R. HARRISON, M.A. PARISI, and S.D. HARRIS, "Intelligent Real-time Sensor Control," Naval Air Systems Command, Washington D.C., March 1991.
- HEFLEY, W.E., "Apprenticeship Instruction through Adaptive Human-Computer Interaction," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 229-239.
- HENDERSON, T.C., "Multisensor Knowledge Systems," *Proceedings: Sensor Fusion*, Bellingham: The International Society for Optical Engineering, 1988, pp. 204-210.
- HOGARTH, R.M., *Judgment and Choice*, 2nd Edition, Chichester: John Wiley & Sons, 1987.
- HORNBERGER, J.L., LT,USN, *Understanding SEW and its Implications for Future Naval Warfare*, Masters Thesis, NPS, Monterey, CA, September 1992.
- HUBER, "A Theory of the Effects of Advanced Information Technologies on Organizational Design, Intelligence, and Decision Making," 1990, CC4001/2 Class Notes.
- IYENGAR, S.S., et al., "A Tree-structured Sensor Fusion Architecture for Distributed Sensor Networks," *Proceedings: Sensor Fusion III*, Bellingham: The International Society for Optical Engineering, 1990, pp. 126-135.
- JACKSON, PETER, *Introduction to Expert Systems*, 2nd Edition, Wokingham: Addison-Wesley Publishing Company, 1990, pp. 4-5.
- JOINT TACTICAL COMMAND, CONTROL, AND COMMUNICATION AGENCY, *Tactical C3I Configuration Management*, November 1987.
- JOHNSON, D.H., et al., "Real-time Blackboards for Sensor Fusion," *Proceedings: Sensor Fusion II*, Bellingham: The International Society for Optical Engineering, 1989, pp. 61-72.
- JOHNSON-LAIRD, P.N., *The Computer and the Mind: An Introduction to Cognitive Science*, Cambridge: Harvard University Press: 1988.
- JOHNSON-LAIRD, P.N., *Mental Models: Towards a Cognitive Science of Language, Inference, and Consciousness*, Cambridge: Harvard University Press: 1983.
- KAHNEMAN, D. and A. TVERSKY, "On the Study of Statistical Intuitions," *Judgment Under Uncertainty: Heuristics and Biases*, edited by D. Kahneman, P. Slovic, and A. Tversky, Cambridge: Cambridge University Press, 1982, pp. 493-508.
- KAHNEMAN, D. and A. TVERSKY, "Intuitive Prediction: Biases and Corrective Procedures," *Judgment Under Uncertainty: Heuristics and Biases*, edited by D. Kahneman, P. Slovic, and A. Tversky, Cambridge: Cambridge University Press, 1982, pp. 414-421.

- KLEIN, "Strategies of Decision Making," 1989, CC4001/2 Class Notes.
- LAKIN, W.L., and J.A.H. MILES, "IKBS in Multi-Sensor Data Fusion," *International Conference on C3: Advances in Command, Control and Communication Systems - Theory and Applications*, London: IEE, 1985, pp. 234-235.
- LAMBERT, D.R., *A Cognitive Deception Model for C3CM*. Naval Ocean Systems Center, February 1987.
- LEVINE, R.Y., *Neural Net Sensor Fusion*, MIT, 1991.
- LINDGREN, A.G., *Data Fusion in a Multisensor-Multicontact Environment*, Rhode Island UNIV., 1986.
- LOESCHER, M.S., LCDR, USN, "Copernicus Offers a New Center of the Universe," *Proceedings*, January 1991, VOL 117/1/1,055, pp. 86-93.
- LOESCHER, M.S., LCDR, USN, *Space and Electronic Warfare: A Navy Policy Paper on a New Warfare Area*, Space and Electronic Warfare, Office of the Chief of Naval Operations, Room 5B740, the Pentagon, Washington, D.C., 20350-2000, April 1992.
- LONG, L. and N. LONG, *Computers*, 3rd Edition, Englewood Cliffs, Prentice-Hall, 1993.
- LUO, R.C. and M.G. KAY, "Multisensor Integration and Fusion: Issues and Approaches," *Proceedings: Sensor Fusion*, Bellingham: The International Society for Optical Engineering, 1988, pp. 42-49.
- MacCRIMMON, K.R., et al., "Second Generation Creativity Support Software," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 219-228.
- MACKE, VADM, USN, "C4I For The Warrior," A brief presented as an SGL at the Naval Postgraduate School, Monterey, CA, August, 1992.
- MAREN, A.J., et al., "Hierarchical Data Structure Representation for Fusing Multisensor Information," *Proceedings: Sensor Fusion II*, Bellingham: The International Society for Optical Engineering, 1989, pp. 162-178.
- MAYERSAK, J.R., "An Alternative View of Munition Sensor Fusion," *Proceedings: Sensor Fusion*, Bellingham: The International Society for Optical Engineering, 1988, pp. 64-72.
- MONK, ANDREW, ed., *Fundamentals of Human-Computer Interaction*, London: Academic Press, 1984.
- NAYLOR, R.T., "Battlefield Data Fusion," *C3 and Management Information Systems*, London: IEE, 1987, p. 95.

- NCCOSC RDT&E / (NRaD), *Copernicus Functional Description Document (FDD)*, August 1992, Code 405, San Diego, CA, 92152-5144.
- NEUSTADT, R. E. and E. R. MAY, *Thinking in Time: The Uses of History for Decision-Makers*, New York: The Free Press, 1986.
- NOVAK, M., "Liquid Architectures in Cyberspace," *Cyberspace: First Steps*, edited by M. Benedikt, Cambridge: The MIT Press, 1991.
- ORR, G.E., *Combat Operations C3I: Fundamentals and Interactions*, Maxwell Air Force Base: Air University Press, 1983.
- PAGELS, HEINZ R. *The Dreams of Reason: The Computer and the Rise of the Sciences of Complexity*, New York: Bantam Books, 1988.
- PAWLICKI, T., "A Neural Network Architecture for Evidence Combination," *Proceedings: Sensor Fusion*, Bellingham: The International Society for Optical Engineering, 1988, pp. 149-153.
- PEARSON, J.C., et al., "Neural Network Approach to Sensory Fusion," *Proceedings: Sensor Fusion*, Bellingham: The International Society for Optical Engineering, 1988, pp. 103-108.
- POWELL, G.M., et al., "ARES: Artificial Intelligence Research Project," *Artificial Intelligence and National Defense: Applications to C3I and Beyond*, Washington, D.C.: AFCEA International Press, 1987, pp. 122-133.
- PULAT, B.M., *Fundamentals of Industrial Ergonomics*, Englewood Cliffs: Prentice Hall, 1992.
- RAGHAVAN, S.A., "A High Level Framework for Developing DSS Workbenches," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 505-516.
- RHEINGOLD, H., *Virtual Reality*, New York: Touchstone, 1991.
- RICE, T.E., *U.S. Coast Guard Integrated Operations Center: Data Fusion in a Network Architecture*. Masters Thesis, NPS, June 1990.
- ROGGERMAN, M.C., et al., "Approach to Multiple Sensor Target Detection," *Proceedings: Sensor Fusion II*, Bellingham: The International Society for Optical Engineering, 1989, pp. 42-52.
- SAGE, A.P., *Decision Support Systems Engineering*, New York: John Wiley & Sons, Inc., 1991.
- SANDERS, M.S., and E. J. MCCORMICK, *Human Factors in Engineering and Design*, 6th Edition, New York: McGraw-Hill Book Company, 1987.

- SANDMAN, THOMAS E., "Induction Support for KBDSS Development: A Proposed System Design," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 4-13.
- SCHENKER, PAUL S., Editor, *Proceedings: Sensor Fusion II - Human and Machine Strategies*, Bellingham: The International Society for Optical Engineering, 1989.
- SCHOESS, J. and G. CASTORE, "A Distributed Sensor Architecture for Advanced Aerospace Systems," *Proceedings: Sensor Fusion*, Bellingham: The International Society for Optical Engineering, 1988, pp. 74-85.
- SHAW, JOHN J., *The Headquarters Effectiveness Assessment Tool (HEAT)*, Lecture Notes, Burlington: AlphaTech, Inc., 1991.
- SHAW, JOHN J., et al., *HEAT User's Manual Revision 2*, Burlington: AlphaTech, Inc., 1991.
- SHNEIDERMAN, B., *Designing the User Interface: Strategies for Effective Human-Computer Interaction*, 2nd Edition, Reading: Addison-Wesley Publishing Company, 1992.
- SHORTLIFFE, E.H., "Medical Consultation Systems," M.E. Sime and M.J. Coombs, Editors, *Designing for Human-Computer Communication*, London: Academic Press, Inc., 1983, pp. 209-238.
- SHUMAKER, R.P. and FRANKLIN, J., "Artificial Intelligence in Military Applications," *Artificial Intelligence and National Defense: Applications to C3I and Beyond*, Washington, D.C.: AFCEA International Press, 1987, pp. 13-32.
- SIKKA, D.I., et al., "Distributed Artificial Intelligence Approach to Object Identification and Classification," *Proceedings: Sensor Fusion II*, Bellingham: The International Society for Optical Engineering, 1989, pp. 73-84.
- SIME, M.E., and M.J. COOMBS, Editors, *Designing for Human-Computer Communication*, London: Academic Press, Inc., 1983.
- SMITH, C.L., and A.P. SAGE, "Situation Assessment in Command and Control," *Information Technology for Command and Control*, edited by S.J. Andriole and S.M. Halpin, New York: IEEE Press, 1991, pp. 449-465.
- SPACE AND NAVAL WARFARE SYSTEMS COMMAND, "Battle Management Architecture 2015 - "A Way Forward", October 1989.
- STARR, S. H., "Synthetic Environments and C2," Information Briefing to Students of the Joint Command, Control, and Communications curriculum at the Naval Postgraduate School, Monterey, CA, 18 February, 1993.
- STEINBERG, A.N., "Sensor/response Coordination in a Tactical Self-protection System," *Proceedings: Sensor Fusion*, Bellingham: The International Society for Optical Engineering, 1988, pp. 115-122.

"The Ghost in the Machine," *The Economist*, Volume 327, Number 7810, May 8th-14th, 1993, p. 92.

TILLQUIST, J., et al., "An Information Indexing Taxonomy and the Image Data Type," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 246-257.

TURBAN, E., *Decision Support and Expert Systems: Management Support Systems*, 2nd Edition, New York: Macmillan Publishing Company, 1990, pp. 669-670.

WALDEN, P., "Rule-Based Expert Systems in Strategic market Management," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 111-121.

WALTZ, E. and JAMES LLINAS, *Multisensor Data Fusion*, Boston: Artech House, 1990.

WASON, P.C. and P.N. JOHNSON-LAIRD, editors, *Thinking and Reasoning: Selected Reasonings*, Harmondsworth: Penguin Books Ltd., 1968.

WASON, P.C. and P.N. JOHNSON-LAIRD, *Psychology of Reasoning: Structure and Content*, Cambridge: Harvard University Press, 1972.

WATKINS, P.R., et al., "AI Integration for Enhanced Decision Support," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 133-144.

WEAVER, CHARLES B., Editor, *Proceedings: Sensor Fusion*, Bellingham: The International Society for Optical Engineering, 1988.

WEAVER, CHARLES B., Editor, *Proceedings: Sensor Fusion II*, Bellingham: The International Society for Optical Engineering, 1989.

WICKENS, CRISTOPHER D., *Engineering Psychology and Human Performance*, New York: HarperCollins Publishers, Inc., 1992.

WIDMEYER, G.R., "Executive Support in an Open Loop Control Environment," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE. pp. 166-175.

WINSTON, P.H., *Artificial Intelligence*, 2nd Edition, Reading: Addison-Wesley Publishing Company, 1992.

WOLKOMIR, "Falling into the Gadget Gap - and it's not our fault," *Smithsonian Magazine*, October, 1992.

- WOOLSEY, R.B., "Application of Expert System Technology to an Information Fusion System," *C3 and Management Information Systems*, London: IEE, 1987, p. 85.
- YAZICI, H., K. MUTHUSWAMY, and J. VILA, "An Expert System Approach for Interface Management in Decision Support Systems," *Proceedings of the Hawaii International Conference on System Sciences*, 1992, Volume III: Information Systems: Decision Support and Knowledge-Based Systems, IEEE, pp. 101-110.
- YOUNGERS, M., et al., "Improving C3: The Potential of Artificial Intelligence," *Artificial Intelligence and National Defense: Applications to C3I and Beyond*, Washington, D.C.: AFCEA International Press, 1987, pp. 33-43.

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