Bolt Beranek and Newman Inc.

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The C³–System User
Vol II: Workshop Notes

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Bolt Beranek and Newman Inc.
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THE C^3- SYSTEM USER

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PREFACE, VOLUME II

This volume contains notes from the workshops that were held under Contract No. MDA903-76-C-0207. Section I contains the set of background notes on C3 systems that was distributed to all workshop participants. Sections II through VII contain notes associated with the individual workshops. In each case, the section contains the following items:

a. The list of workshop attendees

b. The letter of invitation that was sent to invitees

c. A set of questions that was sent to invitees along with the letter of invitation

d. A set of notes based on workshop discussions that was distributed to attendees following each workshop.

SECTION I

BACKGROUND NOTES ON C^3 SYSTEMS:

DISTRIBUTED TO

TO ALL WORKSHOP PARTICIPANTS

Bolt Beranek and Newman Inc.

Background Notes for Workshops on Human Factors in Command, Control and Communication Systems

R. S. Nickerson, M. J. Adams, and R. W. Pew

These notes are intended to provide background material for a series of workshops on Human Factors in Command, Control and Communication (C^3) Systems. The workshops are to be addressed to specific topics relating to human factors issues in C^3 system design and operation. The objectives of these meetings are to consider what is known, within the area delimited by the meeting topic, that has important implications for C^3 systems; to identify and articulate unanswered, researchable, human factors questions that relate in a significant way to the effective functioning of these systems; and to interest potential contributors to a research program in this problem area in the possibility of becoming involved.

1. What is a C^3 System?

For our purposes a command, control and communication system is a system, the function of which is to direct the activity of some organizational or operational entity. Such systems are obviously of critical importance in the context of national defense; they are also applicable, however, to a wide variety of non-defense problems such as space flight, commercial air-traffic control,

law enforcement, disaster relief management, and industrial production. The emphasis in these notes is on defense-related C^3 systems.

Department of Defense Directive 5100.30, 2 December, 1971, defines command and control as "the exercise of authority and direction by duly designated authorities." It goes on to say that "These functions are performed through an arrangement of personnel, equipment, communications, facilities and procedures which are employed in planning, directing, coordinating and controlling operational activities of U.S. military forces" (Section IIIB).

Although one typically sees the terms used in concert, it is important to recognize that command and control are not the same things. Control implies a two-way communication capability, whereas command does not. As Edge (1975) points out, a command system need not have a feedback loop, but a control system must. One can issue commands "open loop," and under some circumstances this may be a reasonable thing to do. It is not an acceptable way to do things, however, if one wants to be able to respond effectively to the dynamics of a changing situation. A command and control system must be able not only to convey command decisions to appropriate action units, but to provide for the commander accurate and timely information that is relevant to the mission of his command, and this information must include feedback regarding the effects of commands issued in the past.

Thus, the simplest representation of a command and control system would show communication in two directions--from command to action units and from action units to command. In fact, the communications requirements of modern command and control systems are very great and the systems that are being developed to meet these requirements are extremely complex. The general acceptance of the tri-partite description--command, control and communication --is an acknowledgment of the absolute dependence of command and control on adequate communication facilities.

It is generally recognized that computer technology also has far-reaching implications for the military, and for plans and programs relating to national defense. So dependent are modern command and control operations on computers that some writers have suggested that the term "C^3 systems" is something of a misnomer, and should be replaced with the more accurate "C^4 systems," the fourth C obviously standing for Computer (Williams, 1975). Other writers have noted that the line of demarcation between communications functions and computer functions is becoming increasingly blurred (Robbins, 1975). In these notes we retain the C^3-system designation as a matter of convention, but we recognize the criticality of the computer's role in such systems.

2. Crisis Management and Crisis Prevention, the Dual Roles of C^3 Systems

One role of military C^3 systems is to direct forces during times of military action. Another is to provide decision makers with the information and tools that can help them anticipate, contain and solve problems before they erupt into military confrontations. We might refer to one of these functions as crisis management, and to the other as crisis prevention.

The first of these roles is perhaps more in keeping with prevailing conceptions of what military command and control is all about than is the second. And the importance of this role clearly is great. That the quality of a C^3 system and the skill with which it is used can determine the effectiveness of a fighting force is apparent, and has prompted the use of such terms as "force multiplier" and "multiplier effect" in reference to such systems and to the consequences of their utilization (Clements, 1975; Michaelis, 1975; Reed, 1975).

The second role is at least as important as the first, however. Obviously, the more effective such systems are at crisis prevention, the less need there will be for crisis management. A primary goal for research relating to C^3 systems and operations must be to increase the capabilities of these systems to recognize and deal with incipient problems before they grow to crisis proportions.

3. The World-Wide Military Command and Control System (WWMCCS)

Several systems and system-supporting facilities have been developed to meet U.S. military command and control requirements. Of overriding importance among them, for at least the near-term future, is the WWMCCS. By DoD Directive (5100.30, 2 December, 1971), the WWMCCS is "the system that provides the means for operational direction and technical administrative support involved in the function of command and control of U.S. military forces." In conception, the WWMCCS is a metasystem, linking together and coordinating the activities of all systems that perform functions vital to U.S. military command and control. More specifically, the WWMCCS is to provide "the means by which the NCA and appropriate subordinates may: monitor the current situation to include the status of U.S. and non-U.S. forces; respond to warning and threat assessment; employ forces and execute operational plans; perform attack, strike and damage assessment; reconstitute and redirect forces; and terminate hostilities and active operations" (Reed, 1975).

3.1 Background

The WWMCCS concept was first established by DoD Directive in the early 1960s. The intent was to link the command and control systems that had been, or were being, developed by various commands to a national command and control system that would support the National Command Authorities (NCA), which, at the time, were

the President, the Secretary of Defense, and the Joint Chiefs of Staff. The Directive specified, or at least allowed, a from-the-bottom-up approach to the problem. The Unified and Specified Commands (e.g., European Command, Pacific Command, Strategic Air Command) were authorized to develop command and control systems to meet the particular requirements of their own missions. The systems were to interface so as also to meet the needs of the NCA, but the emphasis was on the local commands.

The approach failed to produce the desired results. In particular, communications did not work well, especially between echelons. The automated data processing (ADP) facilities of the various systems, which had been developed to different specifications and implemented with different equipment, could not be made to function smoothly in concert.

A rethinking of the problem led to the abandonment of the from-the-bottom-up approach and to a move in the direction of centralized planning and control, and of standardization of equipment and procedures. A study directed in 1966 by the Secretary of Defense and conducted by the Joints Chiefs of Staff (JCS) resulted in the decision to procure 35 computers for the WWMCCS from a single manufacturer on a multiyear basis rather than to continue to let each command acquire its own equipment. A contract for this procurement was awarded to Honeywell Information Systems in 1971. The equipment was to be all off-the-shelf, nothing still being researched or under development was to be included.

A new DoD Directive (5100.30, 2 December, 1971) defined the primary function of the WWMCCS to be to support the NCA (which now included only the President and the Secretary of Defense, or their duly appointed alternates or successors). It identified the National Military Command System (NMCS) as the focal point of the WWMCCS, and directed that command and control systems of all other DoD components be configured and operated for effective support of it, as well as for their specific missions. In particular, the Directive required that all communications facilities of these commands be compatible with those of the NMCS. A secondary function of the WWMCCS is to support the command and control systems of the Unified and Specified Commands and WWMCCS-related management/information systems of other DoD components.

The emphasis of this Directive on the priority of the NCA within the WWMCCS mission serves two purposes. First, it mandates that subordinate commands be properly interfaced with the national command so as to be maximally responsive to national priorities. Second, it provides for the standardization and inter-operability that are necessary to support flexible and dynamic shifts in the delegation and exchange of command and control between national and specific command levels (Riceman, 1975).

3.2 Components

The WWMCCS is made up of the following components: The National Command System, the command and control systems of the

Unified and Specified Commands, WWMCCS-related management/ information systems of the Headquarters of the Military Departments; the command and control systems of the Headquarters of the Service Component Commands, the command and control support systems of DoD Agencies, and several non-DoD systems.

3.2.1 The National Military Command System (NMCS)

The purpose of the NMCS is to provide the means by which the primary function of the WWMCCS is to be realized. Responsibility for the establishment and implementation of operational policies and procedures for all components of the NMCS resides with the chairman of the Joint Chiefs of Staff under the direction of the Secretary of Defense.

The NMCS is made up of the following components:

- The National Military Command Center (NMCC): created in 1965, located in the Pentagon, contains Moscow "hotline," General or flag officer present at all times.

- The Alternate National Military Command Center (ANMCC): located at Fort Ritchie, Maryland.

- The National Emergency Airborne Command Post (NEACP): an airplane at Andrews Air Force Base, Maryland, equipped to function as the NMCC in the event that both the NMCC and the ANMCC are disabled.

- Other Command and Control Facilities as may be designated by the Secretary of Defense.

A significant part of the NMCS is the communication linkages among the various centers, and between the centers and other command facilities. Each of the centers must be ready for operation at all times.

3.2.2 Command and Control Systems of the Unified and Specified Commands (including command and control systems of subordinate unified commands and joint task forces)

- Atlantic Command
- European Command
- Pacific Command
  - U.S. Forces, Korea
  - U.S. Forces, Japan
  - Taiwan Defense Command
  - Military Assistance Command, Thailand
- Strategic Air Command
- Readiness Command
- Continental Air Defense Command

3.2.3 WWMCCS-Related Management/Information Systems of the Headquarters of the Military Departments

- Headquarters, Department of the Army
- Headquarters, Department of the Air Force
- Chief of Naval Operations
- Headquarters, U.S. Marine Corps

3.2.4 Command and Control Systems of Headquarters of the Service Component Commands

- Military Airlift Command
- Military Sealift Command
- Military Traffic Management Command

3.2.5 Command and Control Support Systems of DoD Agencies

- Defense Civil Preparedness Agency
- Defense Communications Agency
- Defense Intelligence Agency
- Defense Mapping Agency
- Defense Nuclear Agency
- Defense Supply Agency
- National Security Agency

3.2.6 Non-DoD Systems

The Directive calls for the establishment and maintenance of coordination and liaison with U.S. government non-DoD systems that have functions associated with the NMCS. Such systems or activities include:

- White House Situation Room
- State Department Operations Center
- CIA Indications Office
- U.S. Intelligence Board National Indications Center
- U.N. Military Mission

- Office of Emergency Preparedness National Warning Center
- U.S. Coast Guard Operations Center
- FAA Executive Communications Control Center
- Other designated entities

The NMCS is to receive from these systems protocol, intelligence, diplomatic, and economic information, and to provide them with military information.

The WWMCCS receives surveillance and early warning information from the following systems:

- The Defense Support Program
- The Ballistic Early Warning System
- Over-the-Horizon Forward Scatter Radar System
- SLBM Detection and Warning System

Other systems and facilities may become part of the WWMCCS on a temporary basis during times of emergency or national crisis.

3.3 Responsibilities and Policy Guidance

3.3.1 Director, Telecommunications, Command and Control Systems

Primary staff responsibility for the WWMCCS and WWMCCS-related systems, excepting responsibilities mentioned in the following paragraphs. The Directive originally assigned this responsibility to the Assistant to the Secretary of Defense (Telecommunications); but this position was abolished by Secretary of Defense Schlesinger in January 1974, and replaced by that of Director, Telecommunications, Command and Control Systems.

3.3.2 Assistant Secretary of Defense (Intelligence):

Primary staff responsibility for intelligence collection and reporting systems.

3.3.3 Assistant Secretary of Defense (Comptroller):

Responsible for ADP procurement.

3.3.4 Chairman, Joint Chiefs of Staff:

Responsible for operation of the NMCS (through the Deputy Director J-3, for command and control, a U.S. Air Force General).

3.3.5 WWMCCS Council:

Provides policy guidance for development and operation of the WWMCCS, and is responsible for performance evaluation. Members of the Council:

- Deputy Secretary of Defense (Chairman)
- Chairman, Joint Chiefs of Staff
- Assistant Secretary of Defense (Intelligence)
- Director, Telecommunications, Command and Control Systems (See 3.3.1.)

3.4 Equipment and Supporting Software

Thirty-five off-the-shelf Honeywell 6000 Computer Systems.

The World-Wide Data Management System. Developed under contract by Honeywell. (Emphasis on standardization of both

hardware and software).

Plans call for connecting all of the WWMCCS computers in a network.

3.5 Technical Support

Provided by the Joint Technical Support Activity, a field activity of the DCA. ADP training and logistic support is the responsibility of the Air Force.

4. Focus of C^3 Research and Development

To be effective, a C^3 system must provide for the aggregation and flow of accurate, timely, useful information, both vertically and horizontally within the command and control structure. The system must provide the means by which the commander can: (1) obtain the information he needs to arrive at decisions; (2) disseminate commands to appropriate units; and (3) monitor the outcomes of those commands. Similarly, the system must give units in the field the means for coordinated implementation of commands and assessment of their effects. A major emphasis in C^3 research and development, therefore, has been on the improvement of capabilities for the acquisition, integration, and exchange of information between command posts.

Some of the systems and subsystems that have resulted from the effort to meet these needs are listed in Table 1. These systems are representative of those comprising the WWMCCS network. The

responsibility for planning and approving the acquisition of major C^3 capabilities and for developing an "architecture" for the overall WWMCCS configuration has been given to the WWMCCS Council. This is clearly a demanding task. The problems inherent in the development of a total system configuration of this scope are compounded by the fact that the system must be able to accommodate unpredictable events as well as any changes in national defense policy. In addition, careful consideration must be given to the issues of cost-effectiveness and budgetary constraints. It is not yet clear what the configuration of the eventual WWMCCS will be; the functional goals of the development effort may be expressed in terms of certain qualities that are often mentioned as WWMCCS requirements. Among these are the following: flexibility, responsiveness, security, survivability, credibility and interoperability.

4.1 Flexibility

The emphasis on flexibility directly reflects recent changes in national defense policy. Because of nuclear proliferation and the changing distribution of power, the doctrine of massive retaliation to a major act of aggression against the United States is giving way to one of precise, flexible, controlled response (Clements, 1975). A secondary motivation for the development of a flexible C^3 system derives from the need for cost-effective strategic capabilities. The development of comprehensive,

reliable, real-time communications and ADP facilities should provide command authorities with the ability to take greater advantage of the full range of options open to them.

4.2 Responsiveness

The responsiveness of a C^3 system depends on its capacity to provide the necessary support for the formulation and implementation of plans within the time frame required for strategic or tactical impact. Research and development relating to the responsiveness of C^3 systems is focused on two areas. First, with the goal of assuring that the commander will have access to the information he needs, and can disseminate his orders within the prevailing time constraints, attention is being directed towards improvements in communications technology. Second, with the goal of assuring that the commander's decisions will be based on the best possible information, research is being directed toward determining exactly what that information should include, and how it should be obtained, analyzed, and presented. It is here that the interdependence of communication and computer technology is most clearly seen.

A wide range of research activities is motivated by the need to minimize the time required to obtain, process, transmit and use information. Communications efforts include the development of ultrareliable combat radios and SHF satellite links. Throughout the WWMCCS there is a need for automated message processing,

switching, distribution, and log-keeping. Much effort is directed toward minimizing the "writer-to-reader" time. There is also an interest in minimizing the time for writing, or reading, itself; an interest that is reflected in the investment in voice, video, graphic, and multimedia communications channels and display systems.

Because of the volume and complexity of the information to be transmitted, emphasis is also being placed on the development of computer-to-computer data exchange techniques. This effort is illustrated by the Prototype WWMCCS Intercomputer Network (PWIN). The ultimate goal of the computer network is to yield quick access to multisource information. This goal raises such research problems as: how should one construct a dynamic, event-driven data base; when should one compromise updating for efficient data manipulation; and how should the system be organized so as to be both useful and accessible, as appropriate, to all levels within the command and control network?

4.3 Security

The story of the acquisition by the British of the German Enigma machine in 1939 and the breaking of the cypher in which the German military command transmitted its most sensitive information and secret orders is only beginning to come to light (Winterbotham, 1974). The criticality of this event in determining the outcome of World War II will undoubtedly be debated by historians for some time to come. There can be little doubt, however, that the intelligence gained by the Allies by virtue of their unsuspected

knowledge of many of the enemy's most guarded plans and intentions was of inestimable value in the making of many of the decisions on which the general outcome depended. The lesson of Enigma is that communications are of doubtful worth unless they can be secured from interception by hostile forces.

Primarily for reasons of security, military communications systems have typically made use of some sort of non-voice transmission that could be readily encrypted. Non-voice methods of person-to-person communication are widely believed to be inefficient as compared to voice, however, and this belief is beginning to be substantiated by data obtained in laboratory experiments (Chapanis, 1971, 1973; Ochsman & Chapanis, 1974). The need for secure voice communications for use in C^3 systems has been recognized by many military writers (Albright, 1975; Reed, 1975; Williams, 1975). Considerable effort is currently being directed toward the development of methods of speech encoding that will make digital transmission--and, consequently, end-to-end encryptón of speech--practically feasible. Much progress has been made on this problem; it is now possible to transmit speech that is highly intelligible at around 1000 to 2000 bits per second, and the bit rate is likely to be reduced further. The resulting speech may not sound like that of the speaker, however, and it remains to be seen what problems will be encountered when an attempt is made to introduce it into operational systems.

4.4 Survivability

The triple redundancy represented by the NMCS, the ANMCC and the NEABCP illustrates the concern for the importance of having a National Military Command System that can survive a massive military attack on the United States. The Advanced Airborne National Command Post (AABNCP), a planned replacement for the NEABCP, represents an attempt to increase the survivability of C^3 operations still further. The AABNCP will differ from the NEABPC in several respects, among them the following: increased communications capability (e.g., SHF satellite communications terminal), more effective protection from electronic countermeasures, greater endurance, and a larger battle staff area.

4.5 Credibility

The point of developing systems such as the WWMCCS is to provide decision makers with the information and tools that will permit them to assess situations accurately and to make the best possible choices among the decision alternatives that are open to them. How effectively an individual uses the information and capabilities that such a system provides will depend, in part, on the degree of credence that he gives to the information it supplies and the amount of confidence he has in its ability to perform as advertised.

While credibility must depend, in the long run, on demonstrated performance, it may, initially, be influenced by many factors in

addition to the intrinsic merits or limitations of a system. Some insight into this problem is provided by a study conducted by Morton (1962) in which four retired Air Force and Navy senior officers (three of four-star and one of two-star rank) were interviewed in an effort to obtain a better understanding of how commanders perceive their jobs and how they relate to electronic command and control systems. While all of the interviewees expressed positive attitudes toward technological innovation in general, they volunteered several caveats. Some skepticism was expressed regarding the ability of operating forces to maintain and utilize some of the equipment found in electronic command and control systems. The problem of backup was noted: after building up a dependence on a sophisticated system, what happens if the system fails and it is necessary to fall back on manual procedures? Lack of credence in system outputs was mentioned, but this was perceived to be a problem that could be counteracted, at least in part, by providing commanders with more adequate instruction and training with respect to the systems they are expected to use. A related, but more complex problem, is that of the fear of erosion of authority. One interviewee pointed out that because commanders tend to be generalists, they may lack the specialized technical knowledge to understand fully the algorithms on which a computer-based system's operation depends, and thus feel powerless to influence the rules for system operation. Such observations underscore the need for careful attention to a variety of human

factors problems, and, in particular, to the task of developing man-computer dialog techniques that will permit a commander to interact with a system in ways that do not require a technical training to understand what is going on.

4.6 Interoperability

DoD Directive 5100.30 specifically mandates the standardization, compatibility and interoperability of the subsystems comprising the WWMCCS. One evidence of this emphasis is the designation of a specific computer system, the Honeywell 6000, as the standard machine for the WWMCCS ADP requirements. Another move towards standardization was the decision that one standard terminal system would be specified for AUTODIN use in the Eighties, and a standard, interim terminal system--the Standard Remote Terminal (SRT)--for the Seventies. Still another was the adoption of a standard system--the Automated Multi-Media Exchange (AMME)--for use by Army and Navy telecommunications centers with large traffic requirements (Clements, 1975). The ultimate goal is the implementation of standard equipment, data management systems, programs, terminology and formats throughout the WWMCCS structure. Thus, the specification and procurement of hardware and software that can function in a variety of environments is a focal problem for research and development. There also are important design problems relating to the identification of those points in the system where differences are necessary, where the

advantages of interoperability are outweighted by the costs, or where security, survivability, or other desiderata indicate the utility of dedicated, as opposed to common, channels.

Several new programs and organizational entities have been established to work towards insuring interoperability. A case in point is TRI-TAC, an organization that was created for the express purpose of providing an integrated approach toward the development of tactical systems for the various military services. The goals of TRI-TAC, according to Reed (1975, p. 9), are, "(1) to achieve the necessary degree of interoperability among U.S. tactical communications systems and to resolve the interface with DCS, NATO and other national systems as required; (2) to place in the field in a timely manner newly developed tactical communications equipment to efficiently meet the needs of joint and service-unique missions; and (3) to eliminate unnecessary duplication of service-unique equipment."

5. Human Factors in C^3 Systems

The fundamental purpose of a C^3 system is to optimize the quality of command decisions and the timeliness with which they are made and communicated. From a human factors point of view, therefore, two fundamental questions to consider about any C^3 system at any level of functioning are these: (1) What information should be presented to the users, and (2) How should that information be represented? The first question is one of content: the

second, one of form. These questions give rise naturally to a host of others that lead one into virtually every major area of psychological research: perception, attention, language, memory, decision making, problem solving, motivation. Indeed, the basic human factors problem in C^3 systems is not so much that of identifying what areas of psychological research are relevant--because most of them are--but that of determining what specific research findings (including potential findings) could have truly significant impact on the degree to which these systems meet the needs of their users.

The importance of this focus on the users' needs is recognized by people with developmental or operational responsibilities for C^3 systems. Clements (1975), for example, points out the necessity for attempting to determine exactly what information the National Command Authorities will require in order to deal effectively with specific potential situations. Clements also has challenged the notion that the quality of a decision is likely to be the better the greater the amount of relevant information the decision maker has at his disposal, by noting the possibility of "information overload," and warning against giving commanders more information than they can digest in a fast moving crisis. That more information--even when it is highly relevant to the decision maker's task--does not invariably lead to better decisions has been demonstrated in laboratory experiments (Hayes, 1964).

The evidence that people are rather severely limited in their ability to apply many disparate items of information effectively to decision-making problems illustrates the interdependence of the "what" and "how" aspects of information presentation. The problem of "information overload" may be less one of amount of information and more a question of packaging. Even a small amount of information may exceed the human being's capacity to make effective use of it if it is presented in suboptimal ways; conversely, if it is properly represented, one may be able to deal effectively with very large quantities of it. One of the goals of developers of C^3 systems is to increase the capabilities of these systems to analyze, correlate and integrate data and to present the results to a decision maker in forms that are well suited to his use (Michaelis, 1975).

The workshops for which these notes are intended as background material will focus on a variety of research areas. The goal in each case, however, will be to determine what research should be done in order to maximize the chances that C^3 systems will, in fact, meet user needs.

Table 1. Representative systems and system-supporting facilities that relate to C^3 operations

Department of the Army Command and Control System (DACCS): The Army subsystem that supports the WWMCCS. Its center, the Army Operations Center (AOC) is located in the Pentagon.

Defense Communications System (DCS): RDT&E program involves 10 areas: switching, transmission, terminals, secure communication, satellite subsystem (DSCS), system control, survivability analysis, operations research/model development, network design, and system integration and transition validation (Hoversten, 1975).

Emergency Message Automatic Transmission System (EMATS): System by which National Command Authorities communicate with CINCs in times of crisis.

Fleet Command Center (FCC): Intended to be for Fleet Commander what TFCC is for Ship Commander, and also to provide interface between TFCC and all other data sources.

Joint Tactical Information Distribution System (J-TIDS): Developmental program under Air Force management, ultimately expected to develop a set of communications terminals that will satisfy the requirements of various military platforms.

Military Airlift Command Integrated Management System (MACIMS): System linking computers at six Aerial Ports of Embarkation to computers at Military Airlift Command Headquarters at Scott AFB, Illinois. One hundred and thirty-four remote terminals planned; over 100 currently in operation.

Minimum Essential Emergency Communications Net (MEECN): The portion of the WWMCCS that is considered survivable of a heavy nuclear attack on the United States, and equipped to send command messages to nuclear forces. Development is the responsibility of the MEECN Systems Engineer of the DCA.

Modular Automated Communication System (NAV-MACS): System being developed (at several levels) by Naval Electronic Systems Command to automate such functions as message processing, switching, reproduction, distribution and record keeping. Built for shipboard use around the AN/UYK-20.

Prototype WWMCCS Intercomputer Network (PWIN): Mini-computer network being developed by JTSA for the purpose of studying internetting requirements of WWMCCS, and for testing software.

Remote Job Entry Terminal System (RJETS): Air Force system providing remote access to Burroughs 3500s and UNIVAC 1050s located at host bases. RJETS are mini-computers; 180 such terminal systems are planned.

Shipboard Data Multiplex System (SDMS): General-purpose information transfer system being developed by the Naval Sea Systems Command for internal data, voice and video intership communication requirements.

Tactical Flag Command Center (TFCC): An on-ship center (under development) that is intended to receive data from a variety of sources (e.g., Ships Signal Exploitation System, Naval Tactical Data System, Integrated Operational Intelligence Center, Carrier Tactical Support Center, Ocean Surveillance Systems, Task Force Sensors) correlate them, and present results to the commander. Plans call for exploitation of advanced computer and display technology.

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SECTION II

NOTES FROM WORKSHOP 1

TOWARD A BEHAVIORAL MODEL OF A C^3 SYSTEM

7, 8 April 1976

BBN, Arlington, Va.

Bolt Beranek and Newman Inc.

C^3
Workshop #1
7,8 April 1976
BBN, Arlington, Virginia

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Dr. Craig Fields	DARPA
Dr. Richard Hayes	C.A.C.I. Inc.
Ms. Carol Keegan	Science Applications, Inc.
Dr. Joseph Markowitz	Self
Mr. Kenneth Plant	Science Applications, Inc.
Dr. W. H. Shawcross	Decisions and Designs Inc.
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Dr. Richard Winterberg	Self
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Bolt Beranek and Newman Inc.

19 March 1976

We are currently engaged in a project for the Human Resources Office of the Defense Advanced Research Projects Agency on the topic of Human Factors in Command, Control and Communication (C^3) systems. A major objective of the project is the development of a plan for a program of research on this topic. It is not our purpose to design C^3 systems, but, rather, to identify researchable problems relating to the performance of C^3 systems, and in particular to that of the users of these systems.

As one means to this end, we are convening a series of workshops to bring together small groups of appropriate individuals to discuss various aspects of the problem. The first such workshop will be held in Arlington, Virginia (BBN office at 1701 North Fort Myer Drive) on April 7,8, 1976. The purpose of this meeting will be to develop a better understanding of C^3 systems, and of the types of human factors issues that have been, or are likely to be, encountered in their design and use.

The meeting will be relatively informal. What we want is a far-ranging discussion of issues that participants consider to be germane to the general topic. To provide a context and some points of departure, we have drafted a brief background paper on C^3 systems, and prepared a list of questions that are representative of those that we would want to cover at the meeting. Both of these documents are enclosed.

My reason for writing you is to invite you to participate in this meeting. Our plan is to limit the number of participants to approximately 12 to 15, so we can maintain a lively discussion

in an informal atmosphere. We have tried to select a group that includes some people who have had experience with C^3 systems as either researchers or users, and others who have done human factors work that, while not explicitly addressed to C^3 problems, seems especially relevant to them in some way.

Any additions you might like to make to the questions listed on Enclosure 2 would be most welcome. If you mail them to me, I will see that they get incorporated in an amended list that will be distributed at the meeting. Alternatively, you could bring them to the meeting and we can amend the list on the fly. Of course, my preference is for the first option, but, being a realist, I will settle for the second.

If you would like to participate in this meeting please let me know as soon as possible by returning the enclosed postcard, and I will give you details concerning place and time. We will, of course, reimburse you for reasonable expenses incurred as a result of your participation (travel, meals, lodging) and can offer you an honorarium of $150 per day. Perhaps the more significant motivation for participation is the chance to help shape a new DARPA program that is likely to provide research opportunities for human factors specialists in the future.

I sincerely hope that you will be able to join us on April 7. In any case, I would appreciate an early reply, because if you are unable to attend, we want to extend the invitation to another potential invitee.

Sincerely,

Raymond S. Nickerson
ftm
Enc. Background paper
List of questions
Self-addressed stamped postcard

Bolt Beranek and Newman Inc.

Workshop #1: Toward a Behavioral Model of a C^3 System

The primary purpose of this project is to develop a plan for a program of research on human factors in C^3 systems. As a first step toward this objective we wish to address the general question of how best to conceptualize a C^3 system, given the intent of focusing on human factors issues and problems. The following specific questions are representative of those that we think should be discussed at our first workshop. If you agree to participate in this workshop, we invite you to modify, and add to, this list as you see fit.

1. Is it possible to develop a model of a C^3 system that would be general enough to be representative of a variety of actual systems, but still detailed enough to have some practical value?

2. If it is possible to generate such a model, what would its major structural and functional components be? And what kinds of measurements could be made to validate, or invalidate, it?

3. If such a model is not a possibility (i.e., if particular C^3 systems are sufficiently diverse to preclude being represented by the same formalism), is it possible to identify system types that are sufficiently similar to be represented by a common model?

4. What kinds of formalisms are best suited to the representation of C^3 systems?

5. What non-military C^3 systems would represent worthwhile objects of study? To make a worthwhile study, a system should probably be dealing with a relatively complex command and control problem; and it, as well as documentation describing it, should be readily accessible to investigators.

6. What techniques are best suited to the study of operational C^3 systems?

7. What behavioral indices are most likely to be useful for such a study? To be useful an index must be obtainable and interpretable.

8. What aspects of the performance of C^3 systems are most constrained by human limitations, or vunerable to human error?

9. How does one determine points of vulnerability before consequential errors have occurred?

10. What methods are used, or could be used, to evaluate the overall performance of a C^3 system?

11. How could those methods be improved?

12. How important is it for a user of a computer-based system to have a basic understanding of what a computer is and how it operates?

13. What are the major human factors issues relating to C^3 organizations and operations?

14. What sorts of taxonomies (task, decision, message, etc.) would be most helpful for describing C^3 systems?

15. In what significant ways do non-military C^3 systems correspond to (differ from) military C^3 systems?

16. What are the critical communications patterns in C^3 systems?

17. Where are the degrees of freedom in C^3 operations? Which of the operations are carried out in accordance with prespecified inflexible procedures, and which require initiative and discretion on the part of the operator?

18. What are the classic failure modes of C^3 systems?

19. What are the information requirements and information sources for C^3 systems?

20. What known human factors principles are applicable (have been or should be applied) to the design and operation of C^3 systems?

21. What unsolved human factors problems are most urgent for C^3 systems?

22. What manual backup provisions are typically made for coping with failure of electronic components of C^3 systems?

23. What general principles guide the allocation of C^3 functions to men and machines?

24. What specific C^3 systems would make the most reasonable foci for study, given the goal of identifying human factors problems, the solutions to which would have significant impact on national defense?

25. How does one tell in advance whether the solution to a particular problem will have a significant or an inconsequential impact on overall system performance?

NOTES FROM APRIL 7,8 MEETING RE HUMAN FACTORS IN C^3 SYSTEMS:

1. The cost and character of a solution to a C^3 problem will be a determinant of, and/or determined by, the level within the DoD command structure at which the solution is to be applied. In order to maximize the chances of extendability of findings to different levels, one might intentionally focus on problems that tend to characterize the middle of the hierarchy.

2. Some C^3 systems that might provide foci for study: TOS, ASSIST, WWMCCS, AWACS, TFCC, CS-3, TACFIRE, ATC-FAA, MAT, NATO, NORAD, NTDS, MTDS.

3. Comment of participant re TOS: Major problems were related to information overload and to the difficulty of coding incoming information. Coders were apparently unable to organize information effectively for system input. They found it difficult to abstract for fileability, retrievability, meaningfulness, or to anticipate commanders' questions.

4. A suggested set of C^3 system functions:

a. data-management functions (includes question-answering capability)

b. aids to documentation, and, in particular, message production

c. aids to communication

d. aids for scheduling and resource management

e. aids for conferencing

f. computerized tools for doing calculations

g. aids for modeling (to permit the conducting of "what if" types of simulations; to predict the consequences of alternative courses of action)

h. capabilities for training

i. thinking aids (including aids for decision making)

We should think about thepossibility of modifying this list in such a way as to make an explicit distinction between functions that have to be performed and methods by which they are, or could be, performed. The functions would include, for example, data management (including data acquisition, data entry, data manipulatic and dissemination), document production, communication, scheduling, computation, modeling, training, and decision making. With respect to the methods by which these functions are performed one would want to distinguish at least unaided-manual, automated, and interactive. In considering interactive processes, one might want to distinguish among several modes on the basis of whether, or the degree to which, the man or the machine dominates the interaction.

5. The traditional principles of war include: unity of command, mass of force, surprise, maneuverability (flexibility), logistics and intelligence. Question: To what extent do these principles still apply?

6. Another set of concepts in terms of which one could conceptualize C^3 systems are those that we have used with reference

to decision making and training: information gathering, data evaluation, problem structuring, hypothesis generation, hypothesis evaluation, preference specification, action selection and decision evaluation.

7. A distinction was made between algorithms for suggesting commands and algorithms for filtering commands. This strikes me as similar in some respects to the distinction between hypothesis generation and hypothesis testing. Perhaps the more general point is the need for generative or synthetic processes and for derivative or analytical processes. Generative processes include processes for generating hypotheses, for generating models, for imposing structure, for inducing principles, for explicating unstated premises in elliptical arguments, etc.

8. A distinction should be made between commands that specify goals or objectives and those that specify procedures. (Goal-specific versus procedure-specific commands.) In this regard it is of interest to consider what are the bounds on the behavior of any given component in a C^3 system. Presumably, in some cases, the behavior is precisely prescribed by the application of doctrine to specific situations. In other cases, presumably, there is considerable latitude for judgment and choice.

9. One might argue that the primary goal of a C^3 system is control, and that command and communication are means to that end. According to this view, what one is attempting to do is to control some aspect of the world space, and the way one does that is to transmit a sequence of commands to appropriate action units. The effectiveness of a C^3 system then would be evaluated strictly in terms of the degree to which the desired control was realized. Everything else is a question of method. (We should check the literature on control systems to see if we might find something useful in it to apply to the problem of developing a conceptual model of C^3 systems.)

10. The point was made that it is not safe to assume that there is an equitable match between the way in which responsibilities are distributed within C^3 systems and the mechanisms for reward for good performance.

11. A "minimal model" of a C^3 system would include: (1) topology (representing communication structure), (2) media, (3) protocols (message formats), and (4) a reinforcement scheme (motivational structure).

12. In judging the success or failure of a C^3 system it may be necessary to ask: success or failure from whose point of view? The notion is that how success and failure are defined may depend on whether one is looking at performance from above or from below. Or, what might appear to be a successful functioning of a

system from a relatively local point of view might actually constitute a failure from a more global perspective, and vice versa.

13. Among the various ways in which a system can fail are the following:

a. Messages (commands) fail to get to appropriate destinations.

b. Messages are misinterpreted by their recipients.

c. Overloading of some system component: too many messages received by a given recipient. This suggests the need for better methods of message classification and prioritization.

d. Misinterpretation of incoming data; failure to recognize indicator patterns.

e. Results of explicit attempts to deceive.

f. Lack of flexibility; inability to change course or to delay commitment.

g. Inability to respond to unanticipated first-time situations. (e.g., the Pueblo incident, the 121 shootdown, the Czechoslovakian invasion).

h. Lack of credibility of messages.

i. Inability to get from one specific point to another in the communication system.

j. Precedence. The problem of a push-down list that never pops all the way up; the mismatch of upward precedence and downward precedence in a hierarchically organized system.

k. The problem of information inundation.

l. Ineffective or inappropriate reward structure. Motivating factors that are inconsistent with the system's mission.

14. Although voice communication has many advantages in a C^3 system, one of the problems with it at the moment is the inability to produce from it a record of the communication. Individuals who have to act upon commands often want or need some documentary record of the command.

15. A factor that may be very important in the functioning of any C^3 system is the style of operation of the commander. One important dimension on which commanders may differ is the extent to which they are willing to delegate decision-making authority. and in the ways in which they use their staffs.

16. Re human limitations that are relevant to the operation of C^3 systems:

a. People allegedly are not very good at estimating compound probabilities.

b. There is a general class of problems that might be referred to as data-transformation problems. These have to do with taking data that come into the system in a variety of forms and transforming them so that they can be used effectively as system inputs. This might mean, for example, classifying observations and imposing some structure or format on data.

c. The problem of inaccuracy in the reporting of observations.

d. The problem of reluctance on the part of people to consider more than a relatively small set of alternatives that may be open to them. (Example of doctors tending to prescribe from a small set of favored drugs.

e. The problem of inadequate coordination between G2 and G3. The problem of intelligence not always knowing enough about our own situation and activity.

f. The problem of actions sometimes appearing absurd at one level, but reasonable at a more global level.

g. The alleged dependence of the quality of decision making on the tactical advantage or disadvantage at which the decision maker finds himself.

17. Re how to determine points of vulnerability in a system before consequential errors have occurred: One approach that can be taken in simulation exercises is that of stressing specific components of a system and observing the effect of such stress on overall system performance, or of intentionally introducing bottlenecks, or of forcing specific components to malfunction. One might have participants in an exercise whose job it is to attempt to sabotage system performance.

18. Some previous studies of C^3 systems:

a. ARI's field evaluation of 7th Army DEVTOS.

b. The Operational Applications Laboratory's research program on threat evaluation.

c. The human factor's study of the SAGE system.

d. A recent developmental study of the NORAD system.

19. Another approach to the evaluation of system performance is the debriefing of system users following the use of a system in a crisis situation.

20. The problem of recovery (reconstitution of the command structure) following military attack was noted as a serious one.

21. C^3 systems of the future will have to be able to cope with multi-party conflicts.

22. Attention has to be given to the problem of interfacing our own C^3 system with those of our allies and even possibly, to some extent, with those of our antagonists or potential enemies. With respect to the latter possibility, there may be great utility in having antagonists mutually informed, at least in a limited way, concerning each other's plans and activities. It is probably not the case, given the potentially devastating consequences of spasm reaction to a presumed threat, that surprise is always a thing for which one should strive.

23. Some human factors problems in C^3 systems:

a. Too many messages (although we should not assume that the messages a commander receives include all those that he needs).

b. Ambiguous messages.

c. In spite of the fact tht most decisions that must be made are stereotyped decisions, they still prove to be difficult, given the time constraints under which they must be made.

d. The most critical information for a commander, namely geographic information (e.g., maps and overlays) is not being provided very well.

e. Data bases are inadequate. They tend to be out of date and to contain erroneous data, and they are difficult to use, i.e., it is difficult to find anything in them.

f. There is no effective way for distributed groups to solve problems better than do individuals.

24. One approach to the study of existing C^3 systems would be that of specifying in some detail what particular individuals in such systems have to do.

25. Perhaps a critical factor in the operation of a C^3 system is the commander's cognitive model of the system. A question of some interest is that of the extent to which the commander understands, or should understand, the structure and operation of

the system at various levels. It seems fairly clear that he must understand them at some level, but it is not clear that he need understand them at all levels. Is the commander who does understand the system at all levels (including, for example, the details of operation of individual programs in a computer-based system) able to utilize the system more effectively than the commander who does not have such detailed understanding?

26. A distinction was made between two types of adaptation required of a system. The first might be referred to as tuning; in this case the system adjusts gracefully, and more or less continuously, to either extrinsic or intrinsic stimuli for change. The second type of adaptation involves quantum jumps from one level of operation to another. Such jumps are necessary sometimes in order to respond to crisis situations or unanticipated developments. They may involve changes in goals and priorities as well as qualitative changes in operation.

27. An impediment to maximally effective C^3 systems can be the existence of conflicting goals at different levels within the system. Such conflicts usually do not result in the explicit disobeying of orders, but, rather, in creative insubordination (equipment failure, accidents, foul-ups of various sorts for which responsibility cannot be fixed).

28. Perhaps the commander's most difficult, and most important task, is that of developing an appropriate conceptualization of the situation. By an appropriate conceptualization we mean one that accurately represents the situation at the level(s) of detail that is consistent with the factors that a commander must weigh in making decisions. It is not necessarily the case that the more detail a model represents, the greater its usefulness will be.

29. A dimension in terms of which C^3 systems can be compared is the degree to which decision-making responsibility is centralized, as opposed to being distributed among various system components.

30. Competition among commanders should not be overlooked as a factor that can influence their performance. An interesting question of some importance for C^3 systems, and for other systems and organizations as well, is the following one: At what level(s) within the system should competition among system units be tolerated or even encouraged? More generally, how can competition be used to improve system performance instead of being divisive and counter-productive?

31. Is a multiprocessor computer system a useful analogy to apply to the problem of assigning tasks among the units of an organization?

32. A factor that needs to be considered in the design of multi-nation C^3 systems is that of the implications of specific languages for thinking. The question is, to what extent does language constrain one's thought processes, and also what of importance may get lost in the translation from one language to another?

33. A key problem of any decision-making situation is that of explicating the value space in terms of which choices will be made. The problem is to determine and make explicit the worth that the decision maker attaches to the various possible decision outcomes. This is a nontrivial problem, and one that probably is not solved simply by asking a decision maker to assign utilities to a set of outcome possibilities.

34. Consideration should be given to the possibility of using a production-rule model to develop simulation models of C^3 situatio In particular, Rand Corporation's terrorism model, which is written in an "if .., then" formalism should be reviewed.

35. The question of how physiological factors affect problem solving and decision making should be investigated, as should the question of how cognitive performance is affected by mental and/or physical fatigue.

36. One way to define a goal is as a desirable future world state. An advantage to this definition is that it leads to a natural measurement of progress resulting from goal-directed behavior, namely, the amount by which the distance between a current world state and the desired world state (i.e., the goal) is thereby reduced.

37. One may view a C^3 system as a tool in the hands of the commander. Alternatively, one might view the system as including the commander as a component. Do these views lead to different approaches in the study and/or operation of C^3 systems?

38. The following set of elements was proposed as basic components of any C^3 system: (a) goals, (b) procedures, (c) action elements (both hardware and people-ware), and (d) communications channels.

39. With regard to the desirability of developing a structural model of C^3 systems, it was pointed out that it is important to recognize that dramatic changes in C^3 activities may alter the structure of a system as well as its modes of operation.

40. It is important that a commander be given the right amount of information--as much as he needs, but not more than he can assimilate. Given the large amounts of information that typically are relevant to the situations in which a high-level commander might find himself, it is essential that much of the

information coming into a system be filtered or partially processed before reaching the commander. How important is it that a commander understand where and by whom the filtering and processing are done, and to understand the details of the filtering and processing techniques that are used?

41. The importance of accurate feedback at various levels in a C^3 system was stressed. The absence of feedback was cited as one cause of system, or component, failure. The provision of feedback that is distorted so the commander will hear what he wants to--or at least not hear what he does not want to--was suggested to be a nontrivial problem.

SECTION III

NOTES FROM WORKSHOP 2

PERCEPTION AND INFORMATION PRESENTATION

24, 25 May 1976

BBN, Cambridge, Ma.

Bolt Beranek and Newman Inc.

C^3
Workshop #2
24,25 May 1976
BBN, Cambridge, Mass.

List of Attendees	Affiliation
Dr. Albert Bregman	McGill University
Dr. William Chase	Carnegie-Mellon University
Dr. Lynn Cooper	University of Calif., San Diego
Dr. Howard Egeth	Johns Hopkins University
Dr. Craig Fields	ARPA
Dr. David Getty	Brown University
Dr. David Green	Harvard University
Dr. Jeanne Halpin	SAI
Dr. Raymond Hyman	University of Oregon
Dr. Judith Kroll	M.I.T.
Dr. Joseph Markowitz	Self
Dr. Irving Pollack	University of Michigan
Dr. Sidney Smith	Mitre Corp.
Dr. Harry Snyder	Virginia Polytechnic Institute
Dr. Kathryn Spoehr	Brown University
Dr. Marilyn Adams	BBN, Cambridge
Dr. Carl Feehrer	BBN, Cambridge
Mr. Austin Henderson	BBN, Cambridge
Dr. A.W.F. Huggins	BBN, Cambridge
Dr. Raymond Nickerson	BBN, Cambridge
Mr. Oliver Selfridge	BBN, Cambridge
Dr. John Swets	BBN, Cambridge

Workshop #2: Perception and Information Presentation

The successful operation of a C^3 system depends on the acquisition, assimilation, and communication of many different kinds of information, e.g., sensor data, geographical data, written and oral reports and commands, statistical summaries, etc. At this workshop, we will focus on problems relating to information presentation. The general question is: How should various types of information be presented in order to maximize the efficiency with which it is perceived and used?

In order to provide a stimulus for your thinking about material that might be relevant to our discussions, we have listed some representative topics below, together with a sampling of questions that relate to them. Neither the topic set nor the questions should be regarded as exhaustive, and you are invited to make any additions to either that you feel are appropriate.

1. Written vs. Oral Means of Communication

   What are the differences in memorability of written and spoken discourse?

   How much time and effort does the sender tend to invest in the composition of oral vs. written messages?

   How does the comprehension of oral and written messages differ in terms of effort and reliability?

   How does the speed, efficiency or coherence of message composition differ between dictated, handwritten, or directly typed messages?

2. Methods for Accelerating Information Presentation and Assimiliation.

   Considering both costs and intelligibility, what is the best method for compressing speech? Should the deletion algorithm be time-based, or should it concentrate on less informative parts of the signal like long vowels and pauses? What comparable techniques could be applied to written information?

3. Importance of Nonlinguistic Information in Spoken Messages

How good are people at speaker identification?

What are the critical cues for speaker identification?

What is the prognosis for automatic voice-printing techniques? Can they become a viable security measure?

How important are prosodic features to the interpretability of speech?

How important is the presence of pauses to speech intelligibility at the lexical, syntactic and semantic levels?

4. Attention and Information-Processing Capacity

To what extent can human information processing capacity be increased through multimodal channels? Under what conditions is it decreased?

To what extent can the reliability of human information processing be increased through the use of multimodal channels?

5. Verbal vs. Pictorial Modes of Information Presentation

What kinds of information can be better communicated through pictures than through verbal means?

How do pictures compare with verbal descriptions in terms of speed of interpretation?

What measures might one use to compare the interpretability or memorability of pictures vs. verbal material?

Can reading efficiency be improved by embedding or substituting pictograms or pictures in prose material?

How does the memorability of pictures and prose compare?

What kinds of errors do people make in recalling (verbally reconstructing) pictorial information from memory?

How do different people's reconstructions of pictorial information compare? Are the distortions and omissions entirely idiosyncratic?

How does set or preconception affect the encoding of complex scenes?

In map reading what is the tradeoff between complexity and detail vs. interpretability?

In terms of coding variables what is the best way to integrate static (geographic) information with dynamically changing status information?

What types of information are best presented graphically or pictorially as opposed to verbally or numerically?

6. Interpretability of Various Ways of Displaying Quantitative Information

What factors affect the interpretability of different kinds of graphic representations of data?

What factors affect the interpretability of tabular data?

What kinds of information are most naturally represented in each of these forms?

What kinds of problems do people have in recoding or translating information from one of these forms to another?

What kinds of systematic biases in interpretation are associated with different forms of statistical summary?

How do equivalent representations differ in terms of memorability?

From which kinds of summaries can people best reconstruct the original geographical information?

How can complex interactions among variables be meaningfully represented?

7. Perception and Visual Display Parameters

Can the distinction between integral and separable dimensions be exploited to enhance presentation of information?

What are the relative advantages and disadvantages of large-scale visual displays as compared with small display consoles positioned at individual user spaces?

How should displays of written material be designed in terms of color, contrast, resolution, visual angle and rate of change for readability?

How should these parameters differ according to the viewer's task (e.g., monitoring, searching, browsing, reading for comprehension)?

What should be done in the way of formatting visual layouts (e.g., space and color) to maximize the viewer's ability to organize and remember the information?

8. Search and Selective Information Processing

What is the feasibility of using eye fixation as an input to a computer-driven display, e.g., to use the point at which the user is fixating as control information when he requests additional data regarding something on the display?

How does visual code redundancy affect visual search performance?

How does familiarity with a spatial layout and location of particular attributes on a visual display affect the time to identify an attribute value?

Is there a difference in the ease with which people can monitor ("skim") written vs. spoken material for specific information?

How do visual search processes differ when the target is physically vs. semantically or categorically defined?

How do people scan written material for specific words?

How do people scan written material for semantically defined information?

MEMORANDUM

To: Participants in Human Factors in Command Control and Communications Workshop on Perception and Information Processing

From: R. W. Pew

Subject: Notes from the Meeting

Date: 9 July 1976

Enclosed are the notes from the workshop held on May 24th and 25th. Thank you again for your contributions.

C^3 Memo

Notes from Workshop No. 2: Perception and Information Presentation

The notes that follow attempt to characterize the ideas, concepts, and suggestions that emerged from our 2-day workshop involving individuals interested in basic and applied research on perception and information display. The goal of this paper is to present the ideas introduced rather than to provide a coherent summary of the meeting. It should serve as a reminder to those present of what was presented rather than as a formal elaboration of the results of the conference.

Command, Control and Communications Systems depend heavily on the presentation and communication of information. Commanders and their staff have many requirements for verbal communications both in terms of speech and in terms of formal written messages. Command and Control Systems rely heavily on the presentation of data from sensors in the field. In some cases, these data are in a raw form. In other cases they may undergo several stages of processing and refinement before they are presented for use. Much of the information used by a commander and his staff has a <u>geographical</u> basis. Many issues in information display concern the appropriate way to provide information overlays through maps and charts that indicate the relationship among elements of a task force or plan. Finally much information is summarized in the form of statistics, graphs, charts, and probabilistic estimates. With this background as to the range of potential applications, the group considered a wide range of topics that might be tentatively summarized under the following headings.

1. Taxonomy of classes of information and user requirements.
2. Information integration, perceptualization, and global feature analysis.

3. Basic information processing and mental chronometry.
4. Psychophysics of displays.
5. Monitoring, attention and workload.
6. Information overload.

1.0 TAXONOMY

The importance of working towards a taxonomy of information structures of the sort required in C^3 systems was emphasized. However, the group was able to contribute little of a substantive sort about progress toward that goal. We considered a taxonomy that begins from user requirements. We considered a taxonomy of tools for displaying information as a function of the nature of the information. We considered the possibility of a task analysis leading to a taxonomy and we considered the case of a taxonomy derived from elemental information-processing operations. However, it was pointed out that the usefulness of an information taxonomy is highly dependent on the specifics of the application both with respect to the level of detail at which the taxonomy should be developed and with respect to the most useful perspective from which to derive it.

One possible taxonomy of C^3 activities that was proposed was the following:

Resource allocation
Scheduling
Monitoring
Event classification
Creation and invention

One approach to the problem of taxonomy that was described was the formulation of a computer simulation of the command and control process under study. Such a simulation would provide for the definition of the hierarchical structure of operations leading to finer and finer analysis and perhaps ultimately to the description of the elemental human information-processing operations required. Some skepticism was expressed, however, about the practicality of carrying forward such a simulation for situations as open-ended and unstructured as the typical command and control application.

Dimensions of C^3 system requirements that might have usefulness for formulating taxonomies included:

1. The extent to which possible decisions to be made can be specified in advance and anticipated.
2. The extent to which time stress is a critical variable in performance.
3. The requirement for analog versus digital data abstraction.

2.0 INFORMATION INTEGRATION

The underlying concept that was the focus of this discussion of information integration was the idea that information should be presented in such a way as to make it possible to incorporate it into the user's model of the object or objects under surveillance. Modes of presentation should enhance the coherence among the dimensions of data in order to relate them to the underlying model. It was suggested by several individuals that the archtype of the expert is his ability to conceptualize his activities in a model of the process with which he is working that makes it easy to incorporate new data or information into the model. It is as if the expert is able to detect and operate on more complex patterns at one time than the novice.

Sometimes it is desirable to alter the time scale over which information is presented in order to enhance its coherence or perceptability. This led to a discussion of the possibilities for speeding up speech signals and to the question of the conditions under which speeded speech might be useful in a C^3 system. The following purposes were offered as possibilities.

1. A long message might be monitored for target words in order to find a part of a message to be attended to in more detail.
2. Speeded speech might be used for review of a briefing session where it is desired to browse through the speech signal.
3. Sometimes visual information that is synchronized with speech needs to be presented at a rate faster than real time. Under these conditions it might be useful to speed up the speech accordingly in order to pace it to the time scale in which the visual information is to be presented.

It was agreed that if the chopping algorithm is correctly chosen speech can be speeded up by a factor of approximately 3 to 1 and maintain intelligibility.

Returning to the more general subject of speeded-up visual or auditory signals, the question was raised concerning ways to pick the optimum integration window or the optimum presentation rate. It was suggested that either control of the rate can be given to the user to adapt to his own needs or that it might be possible to define a formal basis for choosing an integration window by considering the rate of change of the phenomenon under

study in relation to the rate of change of the noise in which the phenomenon is imbedded. It was also suggested that at times there might be value in slowing down signals as well as speeding them up. The purpose here would be to defocus attention on the coherent factors to get at other content that may not be evident because of the compelling nature of the coherent events. With respect to speech this was suggested as a possible way to focus on the emotional content of the speech.

Other techniques for enhancing the perceptibility of coherent signals were discussed. At times it may be useful to transform a signal represented in the time domain into one represented in the spatial domain. The common example is the use of a sound spectrogram A further suggestion concerned crossmodal integration. A particular selected feature of the visual display may be a momentarily relevant source of information. As an attention-getting device it might be appropriate to modulate the intensity of that visual feature with a voice signal presented simultaneously so that the voice modulation and the fluctuation of the visual pattern would be coherent with each other.

A topic of some substantial interest was the discussion of the use of facial features to represent multi-dimensional data. Chernoff in two papers in the Journal of the American Statistical Association (1973) has shown that if the attributes of multi-dimensional stimuli are represented in terms of changing features of a set of stereotyped faces, the display of multiple arrays of such faces enhances the observers ability to detect clustering and patterning in the data. It was suggested that the relative simplicity of visual inspection of these facial arrays can work almost as successfully as formal computational algorithms for computing many potential interactions and that the formal

computing algorithm is very expensive and time consuming even with today's high-speed computers.

Howard Egeth (Jacob, Egeth and Bevan, 1976) and William Huggins at John Hopkins University have continued work with these facial representations. Egeth has used a classification paradigm and has shown that classification of data represented in faces is more efficient than representation of the same data in matrices or in terms of multidimensional abstract symbols. There appears to be something unique about the coherence of the faces. He pointed out that while accuracy is higher with faces than with other data display, classification performance is still not sufficiently reliable to make it a particularly useful technique in a practical setting.

3.0 INFORMATION PROCESSING AND MENTAL CHRONOMETRY

The discussion of mental chronometry opened with Bill Chase's presentation of four circumstances in which attempts to develop predictions of the time required for task performance depended primarily on the nature of the data base with which the subjects were operating and on the ways in which they organized themselves to make use of that database, rather than on time required for the elemental information processing operations that were performed per se. The tasks included the analysis of skilled chess players, the analysis of a text-editing problem, and the analysis of the calculating performance of mental wizards. In each case, it was argued that the efficiency of the mental processing depended largely on the way in which they organized the job and only indirectly on the nature of the information processing operations.

Thus it was argued that mental chronometry is not particularly suited for predicting molar behavior from analysis of its microstructure, but it was agreed that it does provide a way of thinking about information processing activities and can tell us something about the way in which information processing elements or structures are integrated and used. It is more of a diagnostic tool than a predictive one.

The question was then raised concerning the conditions under which pictures are a preferred mode of display as opposed to words or verbal material. It was argued that patterns may be more easily related to distinctive response modes, and therefore if compatibility between the visual input and manual output is importan then pictures may be preferred. It was suggested that spatially-distributed information is probably better presented in pictures while information that has a temporal distribution is better presented in printed words or in a speech signal. Words are believed to be useful for reducing biases in perception, and, of course, they are needed to talk about concepts for which corresponding pictorial representations are not available. In a reaction ti paradigm it takes approximately 250 milliseconds longer to name a picture than to name a word and this fact should be taken into account. Of course, it may be misleading because additional processing time may have to be spent in finding the word to name in order to consider the conditions equivalent to those under which pictures are named.

This led to a discussion of Molly Potter's work on the integration of words and pictures into sentences. She has found that under tachstoscopic presentation conditions,

the selected substitution of pictures for words does not substantially reduce the interpretability of a sentence. It seems clear, however, that this capability depends heavily on the redundancy and predictability of the sentence content. It might also be noted that the same principle probably does not apply at the phonemic level, as evidenced by the difficulty of interpreting this expression:  emic.

The question of map reading and interpretability were the natural outgrowth of the discussion of pictures and words, although it occurred at a later time in the workshop. It was repeatedly emphasized that maps and geography form the basis for many of the kinds of displays of interest to a commander and his staff in a C^3 system. An interesting and potentially researchable question centered on how to design maps to aid human inference processes with respect to them. Maps are inherently hierarchical in organization and it was argued that inferences about maps may also be so organized. At different times the user requires different features of a map to be emphasized. It was argued that a map can form a kind of schema for organization of data.

While geography may form the basis for the schematic representation, the geographic orientation may be distorted in order to enhance the interpretability. Figures 1 and 2 are submitted as an illustration of this point. They show two representations of the ARPA computer network. One lays out the sites superimposed on the geography of the United States. The second shows a logical representation of the sites with considerably more detail concerning the characteristics of the individual sites. Both are obviously useful representations for different purposes.

ARPANET GEOGRAPHIC MAP, APRIL 1976

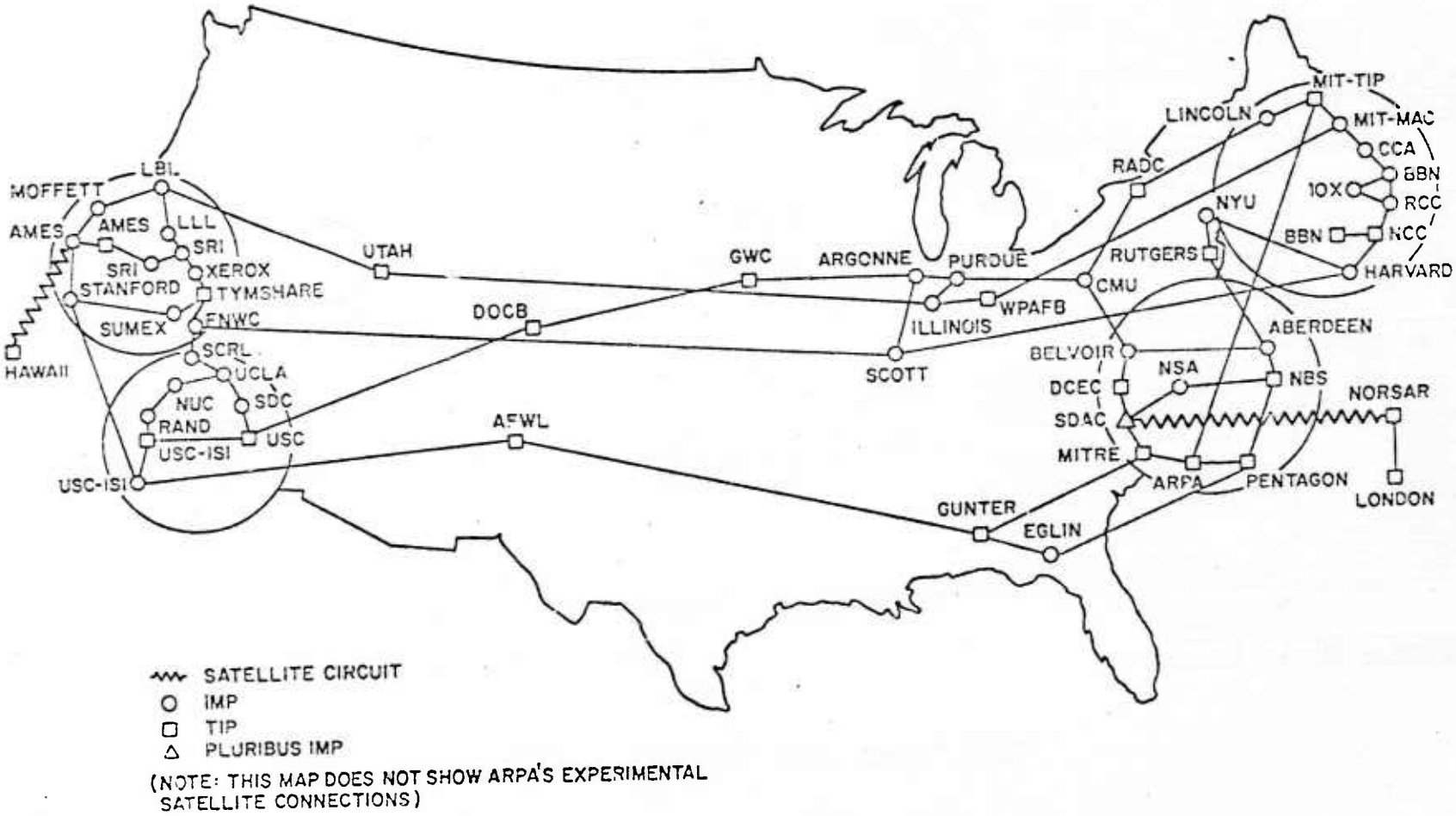
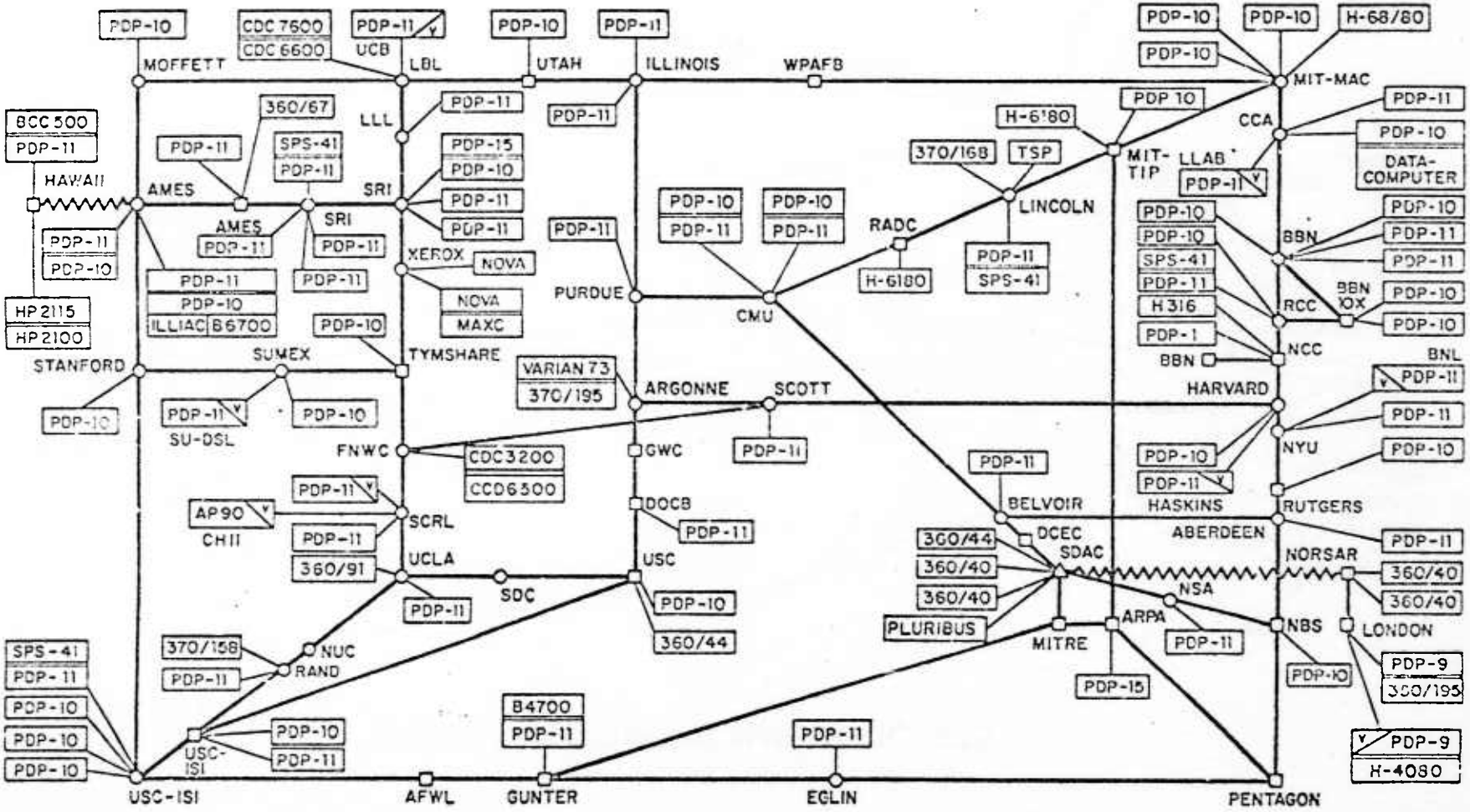


Fig. 1

ARPANET LOGICAL MAP, APRIL 1976



○ IMP △ PLURIBUS IMP
□ TIP ~~~ SATELLITE CIRCUIT

(PLEASE NOTE THAT WHILE THIS MAP SHOWS THE HOST POPULATION OF THE NETWORK ACCORDING TO THE BEST INFORMATION OBTAINABLE, NO CLAIM CAN BE MADE FOR ITS ACCURACY)

A novel concept for the presentation of geographical information at different levels of detail makes use of an extension of the concept of zooming. If the information in a geographical display is represented in the computer hierarchically, it is possible to zoom to different levels in the hierarchy. These levels may correspond to levels of magnification but they may also correspond to different levels of logical detail. Thus one might move from a map of the United States to a map of a particular ARPANET site. Further zooming would then present more detailed information about the characteristics of that particular site, perhaps even characteristics of the computer located at that site. The user would need a technique, such as a pointer, to designate the focus of the expanded scale information, as well as to be able to designate the nature of the more detailed information he desired.

In order to maintain orientation with respect to a geographical display some kind of reference points are required. A question was raised concerning whether the reference points should be static or whether they could be defined relative to the last previous presentation. It was argued that for some purposes the long term conceptualization of the geography and fixed referenced points are important while for other purposes one may be only interested in information relative to the last point examined.

Bill Chase pointed out that a great deal of expertise exists in the National Geographic cartographic group particularly concerning the use of colors, the print characteristics, and so forth. As far as the level of details to be presented was concerned it was asserted that the cartographic service seems to make use of a criterion of the number of details presented per unit area. In areas where the density is great, they present fewer details and in the area where the density is thin they tend to present more details.

The issue of defining fixed reference points led to the discussion of whether maps should be viewed as inside-out or outside-in displays. Taking the outside-in view suggests that maps should always be oriented with north to the top with fixed landmarks always at the same relative position. If one takes an inside-out view, then the map should be oriented so that the user can associate the direction of movement with realistic assessments of left and right. The inside-out view seems most appropriate when maps are used for navigational purposes, however, in command and control applications, maps are seldom used in that sense. There remains, however, the question of whether or not the user's location on the map should serve as the reference point and the map oriented with the field of battle or whatever arrayed about that point as the central focus. This seems like another case for which the answer can only be given in an application-specific case.

With respect to maps, the final question considered was that of suitable means for data entry into a map display. When one needs to enter new data or update old data it becomes necessary to articulate a means for getting those new data to the map in the proper location. While a lightpen or pointing device is suitable for locating positions to enter the data, digital data are most easily entered on a keyboard. Sometimes coordination of a lightpen and keyboard are awkward. It is also necessary, not only to identify the location on the map to which the data refer, but also to designate their location in the supporting database. If these designations are to be made by pointing, then the place where the data are to be entered must be coded with respect to their database category. If, on the other hand, the database category is entered by keyboard, this usually results in a requirement for a multi-dimensional argument to designate the specific location in which it is to be entered. Thus there are a number of combinations of

pointing and keyboard data entry techniques that are useful for data entry in a graphical display. However, this seems like a topic for which further research on the relative effectiveness of alternative data entry techniques would be productive.

4.0 THE PSYCHOPHYSICS OF DISPLAYS

Harry Snyder gave a presentation concerning the current status of efforts to develop quantitative methods for evaluating display quality. His group at VPI has been working on the application of the sinusoidal modulation transfer function for this purpose. Most previous display evaluation methods have focused on the maximum spatial frequency at which bars or sinusoidal modulation may just be detected. However, as Harry points out, this kind of measure focuses on a single point in a space defined by the functional relation between optical response and modulation frequency. There is a large supra-threshhold region in which the optical response characteristics have a significant impact on overall display quality. Harry's group has been working with a measure that corresponds to the area under the curve relating optical response to sinusoidal modulation frequency that lies above the visual detection threshhold. He demonstrated empirically that this measure predicts success at several symbol and target identification tasks by human observers.

His group has also been working with the development of optimal display fonts for dot matrix characters. Previous work has focused on the development of display fonts for stroke characters. Work was described suggesting that, if the constraints of a 5 x 7 matrix are imposed, a font of their own design produces significantly better legibility than the Lincoln-Mitre font which was originally designed for stroke characters.

Dot matrix characters also suffer from the interference of the raster scan lines in a raster scan display. Harry presented data suggesting that the legibility may be improved if a small amount of jitter is introduced in the position of the dots. This has the effect of defocusing the raster lines and softening the overall display thereby improving legibility.

The use of colors for display enhancement was also discussed. For categorical search tasks color has been shown to be better than some other coding dimensions for enhancing the speed and accurac in such a search. Christ (1975) has reviewed the data on color as a coding dimension in a 1975 Human Factors's article. Snyder also asserted that the use of pseudocolor to enhance contrast turns out to be less effective than to directly manipulate the contrast range on a black and white image. Snyder mentioned that in terms of its modulation transfer function, color does not have as broad a response band as direct gray-scale illumination does. Thus, purely from a psychophysical point of view, black and white would be preferred to a single color display. Finally, it was pointed out that the choice of colors as coding dimensions should be selected consistent with the nature of the semantic features to be represented. If a temperature is being represented, it should be in shades of orange-red, if depth of the ocean is being represented it should be darkness of blues, and so forth.

5.0 MONITORING, ATTENTION AND WORKLOAD

It seemed clear to the participants that there are very few jobs in a C^3 system that have the classical properties of the vigilance paradigm. Few individuals monitor radar scopes today. Further, it was asserted that many of the jobs involved in command and control systems do not involve exposure to time pressures. They are more like long-range planning and problem solving activities without a moment-to-moment time constraint. However, some activities might be classified as supervisory monitoring, a job akin to that of the power-plant control-room supervisor. Most of the time there is little to do but when the infrequent critical events occur, the supervisor needs to have full understanding of the current status of the system. Job design to make this continually updated status easy to accomplish is a major challenge. A further challenge to the C^3 system designer is to create conditions that promote the maintenance of operator proficiency for the many different kinds of activities that he might be called upon to perform but which occur very infrequently. Such systems make much use of exercises for this purpose and it was argued that off-line simulation is another effective tool for maintaining proficiency.

The trend in designing supervisory monitoring tasks is to provide alarms or annunciators when a particular state-variable exceeds a preset tolerance. The difficulty is that out-of-tolerance conditions are frequently signalled by patterns of changes in state variables rather than in the behavior of individual state variables. It is very difficult to design alarms that are sensitive to interactions among state variables, especially when these interactions are difficult to anticipate for the range of possible conditions that may be encountered. Here again the problem is to create a

display system that enhances the capability for visualizing the interrelations among task elements, a common theme through much of our discussion of visual information presentation.

6.0 THE PROBLEM OF INFORMATION OVERLOAD

Although not discussed as a separate topic, the problem of dealing with overly rich multi-dimensional sources of information was a theme that materialized at several points during the two-day workshop. It was asserted that a commander has a tendency to focus on only a subset of the information available to him and to formulate hypotheses based on that subset of information. Frequently he will neglect important information that would influence his choice of hypotheses. The problem is exaggerated because once having seized upon a particular hypothesis he becomes committed to it and it takes an inordinate amount of disconfirming data to change the commander's opinion. The design problem is to assure that the commander is presented with the information that is most relevant to the issue he is addressing. But this in turn implies fore-knowledge about what will be important. Techniques designed to preserve the commander's options before a commitment is made would be very helpful at this stage of information management.

If one asks a commander "What information he needs for a particular operation," he is likely to say he needs to have potential access to everything. However, the ultimate in flexibility requires inordinately complex retrieval techniques and it seems likely that a point of diminishing returns will be reached. There is a tradeoff between the amount of information potentially available to the commander and the time that will be required to access it. While good information system design may reduce the severity of this trade-off it cannot eliminate it. This issue not

only involves the design of displays and display format, but also goes to the heart of the question of information retrieval from a database.

7.0 MISCELLANEOUS

A number of questions were raised which are not easily subsumed under the headings identified above. They will be listed here.

1. Are there specific display design considerations that can reduce the difficulty of working under stressful conditions? The traditional argument--that design to take account of stimulus-response compatibility and good human factors practice in general is also likely to be a good design for stress resistance--was mentioned. It was also suggested that a good design for stress conditions, particularly task-induced stress, might involve prioritizing the subtasks in advance so that under time pressure those of lesser importance may be left out. If tasks could be prioritized then the workload could be reduced by design rather than by fiat. A further suggestion considered the possibility of identifying particular tasks that are inherently disruptable under stress. It is these tasks to which particular design efforts should be put and the system made forgiving of disruptions of them. These might be the first tasks for which the possibility of automation would be considered.

2. A researchable issue concerns the development of content-driven communications. It seems likely that artificial intelligence concepts could be applied to selectively channel communications to the individual who is concerned with particular content. If we developed a profile of

interests of a commander and analyzed the content of messages to look for material related to that profile we would reduce the requirement for pre-screening messages and provide a basis in advance for finding the information that is potentially important to a particular commander.

3. A method for identifying the constraints on current C^3 systems was suggested based on an analogy with a study of Paul Rosen on teaching children to read. Rosen analyzed the evolutionary stages that led to modern language from the beginning of time. He then formulated tests of the capabilities required of readers at each stage beginning with elementary pictographs and hieroglyphs and proceeding through phonic and symbolic presentations to the current predominant use of an abstract alphabet. He administered the tests to a set of good and poor readers and found that both groups performed equally well on the tests until they reached the point of using an arbitrary alphabet. The analogy suggests conducting a study of the evolutionary development of C^3 systems having as its goal to identify a point in history at which major breakdowns in effectiveness began to occur and to try to pinpoint those breakdowns with a particular point in the development of the technology used to support such systems. By this means we might identify weak links in C^3 performance and thereby find the point at which to focus the resources for system improvement.

4. In the current international climate the question was raised as to whether there were design considerations that would tend to eliminate the potential for deception and counter measures. It was suggested that perhaps the optimal C^3 system today is one that makes it clear to the enemy what information we have and what our intentions are in a way that precludes the suspicion of deception. Is there a technological means to insure trust in the output of a system? Is there a way to provide group access to a database of information that we want all parties to be aware of and believe in? While clearly we would not want to expose all information in such a way, the ability to expose it in a way that could be guaranteed to be believed might be a signficant step toward avoiding major overreactions.

R. W. Pew
9 July 1976

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SECTION IV

NOTES FROM WORKSHOP 3

MEMORY AND INFORMATION RETRIEVAL

27, 28 June 1976

BBN, Cambridge, Ma.

Bolt Beranek and Newman Inc.

C^3
Workshop #3
28, 29 June 1976
BBN, Cambridge, Mass.

List of Attendees	Affiliation
Dr. Robert Bjork	University of Calif., L.A.
Dr. Alphonso Caramazza	Johns Hopkins University
Dr. Patricia Carpenter	Carnegie-Mellon University
Dr. Alison Fields	ARI
Dr. Craig Fields	ARPA
Dr. Dedre Gentner	University of Washington
Dr. Gary Hendrix	Stanford Research Institute
Dr. Thomas Landauer	Bell Labs
Dr. Geoffrey Loftus	University of Washington
Dr. Joseph Markowitz	Self
Dr. Gary Olson	University of Michigan
Dr. Zenon Pylyshyn	University of Western Ontario
Dr. Lance Rips	University of Chicago
Dr. Robert Shaw	University of Connecticut
Dr. David Waltz	University of Illinois
Dr. Douwe Yntema	Harvard University
Dr. Marilyn Adams	BBN, Cambridge
Mr. Robert Bobrow	BBN, Cambridge
Dr. Allan Collins	BBN, Cambridge
Dr. Raymond Nickerson	BBN, Cambridge
Dr. Richard Pew	BBN, Cambridge
Mr. Oliver Selfridge	BBN, Cambridge
Dr. William Woods	BBN, Cambridge

Questions for C^3 Meeting on Memory and Data Storage

1. What techniques are available for data storage and retrieval that would be particularly useful for C^3 applications?

2. Are any of the methods that are used by AI researchers for representing knowledge in a computer memory sufficiently developed to be practically applicable?

3. What sorts of memory aids would be useful for commanders and other users of C^3 systems?

4. What kinds of browsing techniques could be made available to permit a user of a C^3 system to browse through a data base or some specified portion thereof?

5. What types of problems and difficulties encountered in C^3 operations are most likely to be attributable to human memory limitations?

6. How important is it for a user of a computer data base to have a clear conceptual model of the way the data in that data base are organized?

7. What sorts of techniques can be provided to the user of a very large data base to permit him to create small data structures that are specially tailored to his own needs?

MEMORANDUM

To: Participants in Workshop on Memory and Information Storage

From: R. S. Nickerson

Subject: Notes from meeting

Date: 10 December 1976

Enclosed is a set of notes from the workshop on Memory and Information Storage in C^3 Systems that was held at BBN on 28,29 June, 1976. We have made no effort to produce "minutes" of the meeting, or even to organize the notes in any particular way. We simply jotted down the points that were made, more or less in the order in which they were made at the meeting. Some of them will undoubtedly prove to be a bit cryptic; however, they may serve to complement or supplement your own notes.

I want to thank you for attending the workshop and for your contribution to the discussions. I hope you found it of some value.

ftm

Enc.

NOTES FROM 27,28 JUNE, 1976 MEETING RE MEMORY AND INFORMATION RETRIEVAL

1. There are at least two ways in which research on displays and information presentation relates to the question of memory and information storage.

a. The displays may function in some cases as extensions of memory. A formatted display that is used in conjunction with the user's input to a computer system, for example, may make it unnecessary for the user to remember all the details of the input by prompting him concerning the information that he must supply. Use of map displays also illustrates the point. They extend the user's general memory for geographical relationships and make it unnecessary for him to remember all the details.

b. How information is organized on a display may determine to some degree how well the display's material will be remembered. In general, displays that are consistent with the familiar Gestalt rules of organization will probably be remembered better than those that do not obey these rules. The determination of specific ways in which display organization affects memory performance is an area that could profit from more research.

2. There is a trade-off between structure of information in memory and inference capabilities. Presumably, the more highly structured information is in memory, the more readily accessible it will be, and therefore the less the need for inferencing capabilities.

3. Two assumptions are standardly made concerning memory:

a. That there is no forgetting in long-term memory, and

b. That memory is composed of stable interconnected structures.

4. There is a problem of contradictory information in memory. Suppose, for example, that one stores an hypothesis that is to be tested by incoming data, and the data prove the hypothesis to be false. If the initial hypothesis cannot be forgotten, then the fact that it is false must also be stored. The result is that over time much false information accumulates in memory, and this creates a problem for memory-dependent inferential processes.

5. An ubiquitous problem in the study of memory is that of distinguishing between things that are truly remembered and those that are constructed, or inferred. It is not safe to assume that one can tell the difference with respect to the things that one thinks are in one's own memory.

6. A closely related problem stems from the fact that the act of recall may change a memory trace. This seems especially likely to be true when one has to work to recall something in the first place. The question is, when something is recalled for the n^{th} time, how is the content of that recall affected by the fact that the "same thing" has been recalled n-1 times before?

7. An applied problem that was described is that of determining how best to encode communications between air traffic controllers and pilots, so as to minimize memory loss.

8. There are two general problems associated with the design of displays that are intended to display information that has to be remembered: (a) designing for optimal discriminability or interpretability, and (b) designing for optimal memorability. A question of practical significance is whether designs that meet one of these objectives also meet the other.

9. The point was made that optimality should be defined not only in terms of the probability of error but in terms of the types (magnitudes) of errors that are made.

10. The effects of coding strategies on short- versus long-term retention was mentioned as a general research topic. Presumably, some encoding strategies may work well for short-term retention, but not for long-term retention, and others may do the reverse.

11. In some cases it is important to forget information after it has been used. For such cases, one wants encoding strategies that will facilitate the long-term forgetting.

12. A distinction was made between remembering when one knows the purpose for (use of) the information that is being retained and the case in which the use of that information is not known in advance. Conjecture: knowledge of how information is to be used might facilitate the encoding of that information to maximize its retention and accessibility for that particular use.

13. There may be a difference between remembering facts and remembering how to retrieve facts.

14. The concept of "memory pollution" was introduced. The idea is that the retention and retrieval of important facts may be impaired if memory is clogged up with a great deal of trivia. The notion seems to necessitate one or two assumptions: (a) that memory has relatively small capacity so that the storage of some elements may preclude the storage of others, or (b) that there is a great deal of interference among the stored items of information.

15. One of the difficulties in studying human memory is that of distinguishing between what is remembered and what is produced, i.e., inferred at the time of recall. People are motivated to be consistent and perhaps complete in what they

recall, and therefore may be inclined to interpolate, extrapolate, and in other ways generate information that they do not explicitly remember. Moreover, it is not safe to assume that people can themselves distinguish when they are recalling something from when they are generating it.

16. What people "remember" from events they have witnessed may depend very much on the way in which they are questioned about those events. A skillful questioner apparently may be able to lead an individual to believe that he remembers something that he in fact did not witness.

17. It was suggested that if one wants to do research on human memory (or other memory processes) that will be relevant to the operation of C^3 systems, one might begin by attempting to identify the various types of memory pathologies that are found in these systems. Among the pathologies that one might expect to find are the following:

a. Overconfidence in one's memory and in the ability to retrieve needed information from it

b. Difficulties associated with updating of long-term memory (either human or machine)

c. Poor organization of stored information

d. Insufficiently effective mnemonic aids for getting information out of memory

18. The structure and sequencing of material during presentation are important determinants of retention. In part, because of this fact, the problem of updating memory is difficult because one must be concerned about how the new information fits within the structure that has been imposed on the old information.

19. Relatively little is yet known about mnemonic codes and their effectiveness. This was suggested as a fruitful area for research.

20. The need to develop ways to study memory as it "naturally" functions was stressed. The generalizability of the results obtained in many laboratory studies of memory is highly questionable. One would like to know more about how information that is meaningful to an individual is stored in, and retrieved from, long-term memory for use in tasks that are really significant for the individual.

21. The effect of context on memory is obviously important but not well-understood. One may, for example, be able to remember the combination of a lock with the lock in hand, but not otherwise. Other examples of the importance of context: remembering a musical score, how to get from one place to another, how to accomplish an athletic maneuver.

22. It was reported that people who have to insert data into military computer systems often have difficulty in remembering input codes. Error rates as high as 30% have been obtained in some data input studies.

23. It was reported that doctors typically select all of their prescription drugs from a very small set of alternatives. (The point is not that all doctors use the same small set but that each doctor has his own favorite drugs.) The question is whether this is a result of memory limitations (i.e., the doctor only remembers a few drugs) or the result of a rational memory process in which he has examined a larger set and has decided that the smaller set is adequate.

24. Another general problem that was noted is that of combining effectively information that is stored in human memory with information that is stored in a computer data base.

25. With respect to large data bases that are intended to provide up-to-date information for a user on some particular topic, several problems were identified. Among them are the following:

a. The problem of data capture. Computer-based information systems that work well (e.g., airline ticketing systems, rental car systems, hotel reservation systems, etc.) have the property that <u>all</u> transactions take place via the computer system. That is to say, one cannot get a seat on a plane, or reserve a rental car or a hotel room without going through the system. Consequently, barring malfunctions, one can always assume that the computer system has the latest information vis-a-vis commitments and available resources. Any system that has to rely on voluntary inputs for data update is probably doomed to failure.

b. The problem of searching and retrieving information from a large data base.

c. The problem of discovering from the data base the interesting relationships that are represented only implicitly.

26. Another line of research that could yield useful results is the study of retrieval cues. How can memory best be probed for information that is assumed to be there but proves to be difficult to retrieve?

27. In a discussion of verbal memory, it was pointed out that people seem to be able to remember nouns better than verbs. The errors that are made in verb recall are often synonyms for the verbs that are not recalled correctly. One theory explains this by postulating that the meaning of a verb is represented largely by its effect on a noun.

28. It was pointed out that certain types of intelligence analysts seem to file information under the category "country," and that they use about 100 subcategories per country. There are specialists for countries and for topical areas such as political, economic, etc. In attempting to keep their own data bases current, they search documents for specific indicators. In particular, they look for low-probability events that would tend to indicate significant developments. Special attention is given to descriptors that would be good retrieval cues: dates, names, etc. Attention is also given to the source of

any item of information, and the information is classified in terms of the level of its source. Judgments must be made concerning reliability, concerning what information to retain, and what to discard. Analysts seem to have pretty good ideas about what they might want later and why.

A common memory failure seems to be not adding up all the indicators that one has, even when they are all known by a single analyst. A question that arises is whether computers might help on this problem. They clearly can help on the problem of cross-referencing documents. Might they also help on deciding what data are significant to any particular issue or decision?

29. It was noted that intelligence agents sometimes have a problem of forgetting the problem that they are working on.

30. The sorting of information into nondisjunctive categories (Russian reconnaissance, evacuation plans, etc.) was also noted.

31. A distinction was made between operations that can be performed on knowledge and operations can be performed on data.

32. A general problem of any system or operation that must make use of data from more than one data base is that of integrating the information that comes from the various data bases. The problem is likely to be particularly severe if the different data bases were organized for different purposes.

33. The notion of an "expert" software module was mentioned in connection with information retrieval. An expert module is a software procedure that knows how to answer a specific type of question from a large data base.

34. A human factors problem relating to human interaction with large data bases and question-answering systems is that of defining acceptable interaction dynamics. How often, for example, will users tolerate the response "Don't know," or "Please rephrase your question?"

35. There is a need for a better understanding of memory for structured descriptions. It was pointed out that chess masters have a better ability than others to remember the arrangement of chess pieces on a board, but this is true only if the arrangement is a legitimate one and not otherwise.

36. The point was made that our understanding of memory is likely to be limited until we have a better understanding of what determines conceptual complexity.

37. The assertion was made that a user of a data base should not have to understand the way in which the data are structured in order to use the data base effectively. In keeping with this notion, a system was conceived in which there are three major components:

a. A system interface which represents the point of contact between system and user

b. A data module

c. An intelligent module that contains knowledge about both the system interface and the data, and provides a link between them.

SECTION V

NOTES FROM WORKSHOP 4

STRESS EFFECTS ON C^3 SYSTEM OPERATION

30, 31 August 1976

BBN, Los Angeles, Calif.

C^3
Workshop #4
30,31 August 1976

List of Attendees	Affiliation
Dr. Robert Caplan	University of Michigan
Dr. David Chananie	U.S. Army
Dr. Ward Edwards	U.S.C.
Dr. Craig Fields	ARPA
Dr. David Green	Harvard University
Cm. Robert Kennedy	U.S. Navy
Dr. Richard Lazarus	University of Calif., Berkeley
Dr. John Lyman	University of Calif., L.A.
Dr. Joseph Markowitz	Self
Dr. Carol Mills	SAI
Dr. James O'Hanlon	Human Factors Research, Inc.
Dr. Richard Rahe	U.S. Navy
Dr. Irving Streimer	C.S.U., Northridge
Dr. Barbara Tabachnik	C.S.U., Northridge
Dr. Gershon Weltman	Perceptronics, Inc.
Dr. Christopher Wickens	University of Illinois
Dr. Gerald Zeitz	SUNY, Stony Brook
Dr. Marilyn Adams	BBN, Cambridge
Dr. Sanford Fidell	BBN, L.A.
Dr. Raymond Nickerson	BBN, Cambridge
Mr. Oliver Selfridge	BBN, Cambridge

WORKSHOP ON STRESS EFFECTS ON C^3 SYSTEM OPERATION

The following are representative of the types of issues that we hope to discuss at the workshop in Los Angeles 30-31 August. You are invited to add to the list.

1) To what degree to experiential, personality, and physiological factors determine susceptibility or resistance to stress effects?

2) Can stable, long term personality traits be identified which mitigate effects of stress on individuals?

3) Can similar physiological traits be identified?

4) Can such personality or physiological traits (if they exist) be acquired through formal training?

5) Can individuals possessing such traits be identified?

6) How well can the behavior of particular individuals under stress be predicted by personality or physiological measures?

7) What tasks require what levels of stress for optimal performance?

8) Can a classification of tasks by optimal stress levels be developed systematically?

9) How are specific tasks affected by extreme levels of stress?

10) Which C^3 system tasks are most and least susceptible to degradation by stress?

11) Can the mechanical aspects of C^3 tasks be designed in such a manner as to minimize the stress to which people in C^3 systems are subjected?

12) Can psychotropic (mood modifying) drugs reduce stress in such settings?

13) Can the social setting of task performance be arranged to mitigate stress effects, as, for example, by sharing responsibility, well timed relief schedules, organizational structures, etc.?

14) Are special stress-relieving techniques useful for crisis management?

15) How can commanders and other users of C^3 systems recognize situations in which stress degrades effectiveness? Are such situations predictable?

16) What activities relieve stress while off-duty?

17) Can motivational factors be employed to increase individual or group resistance to stress?

18) What are the correlations among the various measures of stress in common use?

19) Can a single, superior measure be devised or selected on the basis of reliability and universality?

20) Can any measure of stress support quantitative predictions of the magnitude of stress effects?

21) Are communications upward and downward in the chain of command similarly affected by stresses?

SYNOPSIS OF C^3 - STRESS CONFERENCE

Twenty one persons attended the Los Angeles Conference on August 30 and/or 31 in one capacity or another. Names and addresses of those not associated with BBN and ARPA are attached. Participants made informal presentations during which they discussed the relevance of research with which they were familiar to stress problems in C^3 systems, and raised issues which appeared to be of importance for stress research in general. No attempt was made to define the term "stress"; indeed, over a score of specific stressors were discussed in contexts ranging from industrial safety and production, through long term occupational exposure, to societal organization. Some of the viewpoints expressed on the more salient issues are summarized in the following sections.

1. Relative Importance of Chronic vs. Acute Stress in C^3 Systems

The view was expressed that research on acute stresses was most germane to human performance in C^3 systems. Subsequent discussion, although generally in agreement with this view, also made it clear that an individual's ability to cope with acute stress varies with levels of chronic stress. Thus, for example, a commander's ability to deal with an emergency situation depends not only upon the immediate stresses to which the commander is subjected, but also to the commander's experience in handling prior stressful situations and current levels of exposure to long term stresses unrelated to the immediate emergency. It was generally agreed that isolated study of acute stress effects would be of limited benefit.

2. "Realism" in Stress Research

The topic of "realism" in stress research was raised in several contexts. In the context of extrapolation of results of experiments to crisis situations in C^3 systems, many participants

were skeptical. Their skepticism seemed based primarily upon the disparity of levels of stress that could be produced in the laboratory and those to which operational personnel might be exposed.

In the context of the ethics of stress research, the issue of "realism" was seen as a substantial problem to the extent that it required deception of test subjects. Potential means of circumventing rules for protection of human subjects were denounced by some on ethical grounds; others pointed out that even the more extreme forms of experimental stress popular years ago produced little in the way of substantive findings.

It was generally agreed that the hope for future research in this area lay in carefully designed field experiments. The favored paradigm seemed to be long term prospective study of a population exposed (for extra-scientific reasons) to varying levels of actual stresses. Difficulty of access to such populations was discussed at length. A number of military situations which offered such opportunities were suggested.

3. Means of Alleviating Stress

A number of means of minimizing the effects of stress on performance in C^3 systems were discussed. Considerable attention was given to the social context in which people are exposed to stress. Social supports for coping behavior were contrasted among various organizational settings; knowledge of coworkers' performance and workload were discussed from various perspectives; and scheduling of relief personnel and shift length optimization were proposed as potential stress relief techniques. Other schemes, ranging from intentional witholding or delaying of information to engaging in activities that dissipate effects of stress were also mentioned on several occasions.

4. Actual vs. Perceived Stress Levels

An important distinction was made between objective and subjective measures of stress. In most cases, it is the "rit"

of the workload to an individual's expectations of performance abilities which determine the amount of stress experienced. Thus, it may be difficult to infer dosage-response relationships from research that applies the same objective levels of stress to different individuals.

5. Reserve Capacity Model

A common finding in stress research is that test subjects, if sufficiently motivated, are capable of maintaining performance in the face of severe stress for some time. Both anecdotal evidence and experimental results of various sorts were quoted at the conference in support of this finding. There was also some discussion of recent findings that performance decrements may occur after the application of stressors has ceased. The inference was drawn that coping has a cost which may be deferred, but which eventually must be paid.

A "reserve capacity" model was discussed to account for these findings. Although proposed in various forms ("limited stock of psychic energy","finite energy reserves", etc.), it may be simply conceptualized in an hydraulic analogy. A tank of fluid (representing a supply of whatever resources are needed for coping) is drained at a certain rate by coping with stressful situations. It is refilled at same rate (and at some cost) at less stressful times. Experimentation directed at clarification of the dynamics of such a model would seem to be highly useful. First, factors that affect the capacity, draining, and recharging of the tank must be identified. Next, means of quantifying such factors in common terms must be found. Finally, rates of expenditure and replenishment must be established.

SECTION VI

NOTES FROM WORKSHOP 5

DECISION MAKING AND PROBLEM SOLVING

21, 22 September 1976

BBN, Cambridge, Ma.

C^3
Workshop #5
21, 22 September 1976
BBN, Cambridge, Mass.

List of Attendees	Affiliation
Dr. John Bennett	IBM
Dr. Robyn Dawes	Oregon Research Institute
Dr. Baruch Fischhoff	Oregon Research Institute
Dr. James Greeno	University of Pittsburgh
Dr. Reid Hastie	Harvard University
Ms. Susan Haviland	University of Calif., Irvine
Dr. John Hayes	Carnegie-Mellon
Ms. Carol Mills	Science Applications, Inc.
Dr. John Modrick	Honeywell Inc.
Dr. Cameron Peterson	Decisions and Design
Dr. Larry Phillips	Decisions and Design
Dr. George Potts	University of Denver
Dr. John Saalberg	Science Applications, Inc.
Dr. David Schum	Rice University
Dr. James Shanteau	Kansas State University
Dr. Douwe Yntema	Harvard University
Dr. Marilyn Adams	BBN, Cambridge
Dr. Allan Collins	BBN, Cambridge
Dr. Carl Feehrer	BBN, Cambridge
Dr. Raymond Nickerson	BBN, Cambridge
Dr. Richard Pew	BBN, Cambridge
Mr. Oliver Selfridge	BBN, Cambridge

MEMORANDUM

To: Invitees to Workshop #5: Decision Making and Problem Solving

From: Raymond S. Nickerson, Bolt Beranek and Newman Inc.

Subject: Workshop

Date: 25 August 1976

We are engaged in a project for the Human Resources Office of the Defense Advanced Research Projects Agency on Human Factors in Command, Control and Communication (C^3) systems. A major objective of the project is the development of a plan for a program of research on this topic. It is not our purpose to design C^3 systems, but, rather, to identify researchable human factors problems relating to the performance of such systems.

As one means to this end, we are convening a series of workshops to bring together small groups of appropriate individuals to discuss various aspects of the problem. One such meeting is scheduled to be held in Cambridge, Mass. (BBN office at 10 Moulton Street) on September 21, 22, 1976. The purpose of this meeting will be to discuss decision making and problem solving in relationship to C^3 systems. In particular, what we hope to accomplish is the articulation of some significant researchable problems pertaining to this topic in C^3 contexts.

This memo is a follow-up to the invitation you recently received by phone to participate in this meeting. We are very pleased that you have agreed to meet with us and look forward to seeing you on the 21st. We have limited the number of participants to not more than 20 so we can maintain a lively discussion in an informal atmosphere.

What we want at the meeting is a far-ranging discussion of issues that participants consider to be germane to the general topic. To provide a context and some points of departure, we have drafted a brief background paper on C^3 systems, and prepared a list of questions that are representative of those that we might discuss at the meeting. Both of these documents are enclosed.

We plan to devote the first morning, or whatever portion of it is required, to brief (10-15 minute) presentations by participants. While the invitation is not contingent on your agreeing to make such a presentation, we would appreciate it very much if you would be willing to take this time to give your perspective on the general problem. If you wish, you might use the time to introduce possible topics that you feel are especially important to explore during the meeting.

The meeting will start at 9:30 a.m., Tuesday, September 21, and end early in the afternoon of September 22. If you would like us to make hotel reservations for you, please indicate that on the enclosed self-addressed postcard (specify the night or nights), and return it to us as soon as possible. Enclosed is a map of the area to help you find your way to BBN.

Probably the easiest way to get here from the airport is to take a cab. If the driver does not know where Moulton Street is, tell him it is in the Fresh Pond area of Cambridge. We will, of course, reimburse you for reasonable expenses incurred as a result of your participation (travel, meals, lodging) and can offer you an honorarium of $150 per day. Perhaps the more significant motivation for participation is the chance to help shape a new DARPA program that is likely to provide research opportunities for human factors specialists in the future.

See you on the 21st.

Sincerely,

Ray Nickerson

Raymond S. Nickerson
ftm
Enclosures:
Background paper
List of questions
Self-addressed stamped postcard
Map

Workshop #5: Decision Making and Problem Solving

The following are representative of the types of questions that we would hope to discuss at the workshop. You are invited to add to the list.

1. How do the decisions made by groups differ from those made by individuals? What prescriptive frameworks exist for judging group decision making?

2. What heuristics are used by problem solvers and decision makers to infer states of the world? What technique might be employed to help the decision maker understand when these heuristics are appropriate and when they are inappropriate?

3. A characteristic of most information systems is that occasionally they present the problem solver/decision maker with data that are in error. What methods are available or might be developed to aid the user of such data?

4. Many taxonomies and discussions of problem solving and decision making are episodic in nature--that is to say, they view the activities as being comprised of sequences of subactivities (information seeking, data aggregation, hypothesis testing, etc.). Does this approach present an adequate model of the command and control function? What alternative models might be formulated to highlight the inevitable interactions among these subactivities?

5. Most practical problems require that a set of actions, rather than a single action, be taken for a complete solution. Frequently, however, one or more members of the set cannot be defined until a prior member has been identified. How might the decision maker be aided in selecting a consistent set of actions and in identifying critical options as he proceeds?

6. How might an interactive system be configured to help the commander recognize similarities and dissimilarities between a current problem and one(s) he has faced in the past? How might that system aid him to select an appropriate response?

7. What models of human decision making and/or problem solving currently exist in a form suitable for inclusion in a simulation of command, control and communication processes?

8. What decision aids and/or problem solving aids exist that could be used to assist the commander or lower ranking personnel engaged in C^3 activities? What would need to be done to these aids to make them operationally suitable for use?

9. What practical techniques exist for planning and for prediction of outcomes? How might these techniques be effectively implemented in an environment employing interactive displays?

10. What techniques exist for capture and modeling of the inferential and decision processes of problem solvers? Could these techniques be utilized in an interactive system to aid and guide the activity of the commander?

11. Much of command and control consists of:

a) carrying out plans, and

b) elaborating or modifying the plans as the situation develops.

What is known about human strengths and weaknesses in those two activities?

12. How might a computer assist a human operator in performing those activities? How might a human operator assist a computer?

13. How does the individual's conception of the problem bias his search for relevant data?

14. How does the organization of data affect the individual's process of hypothesis generation.

15. What kinds of systematic individual differences are found in problem solving/decision making strategies?

16. To what extent can decision making skills be taught independently of specific decision problems? That is to say, to what extent can such skills be taught in such a way that they generalize across a variety of decision situations?

17. Investigators have discovered a number of ways in which decision makers tend to be biased in their decisions. How can these biases be used to advantage in decision making systems?

18. A distinction can be made between a fundamental human limitation and a tendency on the part of an individual to perform in a suboptimal fashion, even when he has the capability of performing more nearly optimally. How useful might this distinction be in classifying decision making performance and in developing methods for compensating both for human limitations and for stereotyped ways of performing suboptimally?

19. How does one distinguish between reasons for a decision and after-the-fact rationalizations?

20. How can one maximize the probability that incoming information will be assessed objectively and without bias by the decision maker even after he has made a commitment in favor of some hypothesis about the state of the world?

MEMORANDUM

To: Participants in Workshop on Decision Making and Problem Solving

From: R. S. Nickerson

Subject: Notes from meeting

Date: 3 November 1976

Enclosed is a set of notes from the workshop on Decision Making and Problem Solving in C^3 Systems that was held at BBN on September 21, 22, 1976. We have made no effort to produce "minutes" of the meeting, or even to organize the notes in any particular way. We simply jotted down the points that were made, more or less in the order in which they were made at the meeting. Some of them will undoubtedly prove to be a bit cryptic; however, they may serve to complement or supplement your own notes.

I want to thank you for attending the workshop and for your contribution to the discussions. I hope you found it of some value.

ftm
Enc.

NOTES FROM SEPT. 21,22 MEETING RE DECISION MAKING AND PROBLEM SOLVIN

1. Many decision-aiding techniques require that users be able to think in probabilistic terms. They must, for example, be able to evaluate possible states of the world in terms of their relative likelihoods of actualization.

The point was made that people may differ considerably in their ability to understand or use probabilistic notions. In particular, it was suggested that there may be significant cross-cultural differences in this regard, and some data were described to substantiate this view.

Systematic cross-cultural differences in the degree to which people can think in probabilistic terms could turn out to be an increasingly significant issue if command and control operations of the future tend more to involve the interaction of people of various nationalities and cultures with a common system. The assumption that probabilistic terms mean the same things to people of various culture, if in fact they do not, could lead to unfortunate results.

2. Some data were reported on the question of how accurately people can judge their own knowledge. In this regard, the notion of an uncertainty calibration curve was discussed. An uncertainty calibration curve shows how the degree of confidence an individual expresses in an assertion relates to the probability that the assertion is correct. For an optimally calibrated person, this

curve would have a slope of 1, inasmuch as degree of confidence would predict accuracy perfectly. For example, considering all judgments for which an individual was willing to say that the probability of his being correct was .8, 80% of them should be correct.

Uncertainty calibration curves almost invariably have a slope of less than 1. There was some discussion of the factors that appear to affect the slope and intercept of this curve and, in particular of the fact that efforts to train people to calibrate more accurately have been generally unsuccessful.

A question of some interest that seems not to have been resolved yet is whether people who know more (have more facts at their disposal) are also better able to assess their knowledge (have more nearly optimal uncertainty calibration curves). It was agreed that this area is one that could profit from more research.

3. This point relates to both of the preceding ones. Some data were reported that suggest that Chinese people tend to have a discontinuity in their uncertainty calibration curves. More specifically, the curve is relatively flat, except at the upper extreme (i.e., where confidence approaches certainty) at which point the curve turns upward. This finding supports the notion that Chinese people tend not to see the world in terms of probabilities but in a more dichotomous fashion.

4. A distinction was made between the technology available for management-decision problems and that for real-time decision aids. It was suggested that the former technology is years ahead of the latter.

5. A decision aid involving the decomposition of a problem into subproblems that could be solved independently with the use of regret matrices was described. The need for constraints and tree-pruning procedures to contain complex decision problems within manageable limits was noted.

6. An important capability for any general-purpose decision aid is that of performing sensitivity analyses. If one cannot determine, with a fair degree of accuracy, the relative seriousness of various types of errors that are possible, one does not have a firm basis for deciding how much it is worth to attempt an optimal solution to a decision problem as opposed to a suboptimal but readily available one.

7. The following question was discussed at some length: When is it best to use experts' judgments rather than a decision-making algorithm? It was pointed out that in order to apply a decision-making algorithm, one must: (a) choose dimensions in terms of which the decision is to be made, (b) code these dimensions, and (c) integrate the dimensional information that is to be used. Studies comparing the effectiveness of statistical

versus clinical predictions have tended to show statistical comparisons to advantage. It was suggested that experts should be used to choose and code dimensions, and that algorithms should be used to integrate the dimensional information.

8. The role of pattern recognition at various levels of decision making was stressed. This includes the recognition of patterns that can be formed by applying allowed operations to other patterns. The importance of pattern perception in the performance of chess experts was noted as an interesting analogy. It was pointed out that the patterns in this case are not only existing patterns but patterns that can be obtained as a result of admissible operations (moves) on existing patterns. The patterns (to be realized) represent subgoals in the problem solution.

9. It was suggested that there was something of value to be learned from the study of the rules of evidence and jurisprudence that could be applied to C^3 decision problems. One significant way in which jurisprudence and C^3 decisions are similar is in the fact that information is provided in both cases for a variety of reasons, including deception.

10. It was also noted that the study of jury decisions was one approach to the study of group decision maing in general. Some data were referred to that suggest that the deliberation

process by which the jury arrives at a decision may differ depending on the decision rule (i.e., whether the decision is to be based on majority opinion, two-thirds' opinion, etc.).

11. In connection with jury decisions, evidence was cited of selective memory for "facts" that tend to confirm a decision that has been made. There seems to be a question regarding such findings as to whether the effect is a true memory effect or whether it results from a better initial assimiliation of the confirming facts which could have been instrumental in producing the decision in the first place (cart-horse problem).

12. It was noted that a distinction should be made between habit-following and decision-making, and that many of the "acts of choice" that pass for decision-making really are habit-driven. An example is the purchasing of goods, as for example, brand-name canned goods in a grocery store. Selection of Brand X canned peas on any given shopping trip does not necessarily constitute a decision to buy Brand X over alternative brands. It may involve simply carrying out habitual behavior. This may have both desirable and undesirable implications. On the plus side is the efficiency of habitual behavior: it obviates spending the time and energy that would be required to make an independent decision for every action. The negative implication is that it sometimes leads to stereotyped and maladaptive behavior. The point is

well taken that this may have both desirable and undesirable implications.

good: efficient--too much time and work to make real decisions about everything

bad: stereotyped, unadaptable decision-making

13. A common theme in much decision-making research is man's limitations as a decision maker. The multidimensional judging of livestock by experts in an agricultural college was used as an example of how good people can be at decision making. Some evidence was cited that judges used as many as 8 to 11 uncorrelated dimensions in judging the quality of livestock. Why they seem to do so badly with correlated dimensions is unclear.

14. A general challenge to people who would develop problem-solving and decision-making aids is to find ways of getting out of people's heads what they know (but may not know they know) that is relevant (but may not be spontaneously perceived as relevant) to the problem.

15. Some observations were made about the possible role of cognitive style in decision-making performance. The notion was that there may be systematic differences between people that can be characterized in terms of a few dimensions, e.g., abstract-concrete, passive-active, logical-intuitive.

16. It was suggested that automated techniques seldom can be introduced smoothly into existing organizational structures. Their introduction almost invariably necessitates changing the structures.

17. There was some discussion on the question of whether decision aids have to be designed explicitly for specific situations in order to be useful. Aids that could be applied effectively across a variety of situations obviously would be of greater interest than those that can be applied only to a specific problem. There did not seem to be a consensus that general-purpose aids were possible, given the current state of the art and the populace.

18. It was pointed out that one of the major benefits of attempting to analyze a decision situation to the point that a decision model could be applied to it is the better understanding of the problem that the decision maker may get as a result of attempting to do the analysis. This is independent of whether the model or aid proves to be usable or not.

19. The importance of recognizing the hierarchical goal structure of any complex organization was emphasized. It is particularly important to recognize that the goals at one echelon may be different from those operating at another echelon. It is imperative to the effective functioning of any complex system that the goals at different echelons at least be consistent with each other, and that those at the lower echelons be supportive of those at the higher ones.

20. The point was made that increasing amounts of data are being accrued on the way people behave in decision-making situations, but that this research should be extended in two directions: first, there is a need for a mechanism through which research findings can be applied to real decision-making problems; second, having determined the situations in which biases, errors, irrationalities and general foolishness tend to occur, there is a need for psychologists in the fields of memory and cognition to try to discover the psychological processes underlying these tendencies.

21. The problem of cost-benefit incompatibilities was discussed. The National Health Insurance was used to illustrate this point: People are willing to support NHI only if offered at reasonable cost; however, people see the primary (perhaps only) worthwhile benefit of NHI to be in the coverage of small medical fees, such as visits to doctors, dental fillings, etc. These two stipulations are diametrically incompatible; despite this, the resolution will probably be a moderately priced NHI program which covers only moderately expensive costs--a compromise which will not please anyone very much.

22. What seems to be an inability of people to deal adequately with risk assessment was discussed. Despite government-subsidized insurance premiums, for example, it is hard to convince high-risk flood populations that such insurance is a bargain.

23. There was some discussion of the construction of fault trees--contingency trees for which the end branches correspond to the aversive consequences of faults, e.g., failure in nuclear power plant. In constructing such trees there is the problem of how to be sure that every possible end-state (consequence) has been included and of identifying what the consequences of oversight might be.

24. It was noted that there appears to be a set of primitive relevance judgments that people tend to make about the information in a problem statement. One tends, for example, to pay special attention to "ifs," time words, numbers, set descriptors, and the like.

25. An important aspect of problem solving is the ability to classify problems as to type, and to see isomorphisms. When people recognize a problem type, they tend to apply a routine problem-solving frame; the difficulty is they are likely to do this whether or not the application is really appropriate. On the other hand, they often fail to perceive an isomorphism between problems with different surface representations. In these cases, they systematically tend to solve what are really the same problems with distinctively different procedures.

26. The importance of the order of information presentation to decision makers was stressed.

27. Military intelligence reports are supposed to be assessed as to their accuracy and source reliability. It was claimed that analysts cannot, or do not, use both of these dimensions, or at least that to the extent that they do, they tend to integrate them.

28. An analogy was drawn between scientific inference and medical diagnosis; another was drawn between juridical and intelligence proceedings.

29. Among the things that make problems difficult are the lack of definition either of goals or of the problem space. Most decision algorithms require specificity in both cases and surprisingly little attention has been given to situations in which one or the other is not specifiable. Ill-defined problems are likely to be especially prevalent in dynamic situations, in which the problem space is constantly changing, and therefore are especially relevant to command and control systems.

30. In studying or describing the behavior of any man-machine system, it is important to distinguish between goals and procedures. More specifically, it is important to distinguish between those circumstances in which it is sufficient to provide a component of the system with a goal, and leave it to its own devices to achieve that goal, and those in which the component must be provided with a procedure.

31. Some data were reported showing some systematic ways in which people seem to misapply rules of inductive inference.

32. An attempt to generate a list of known or suspected limitations of human decision makers or systematic errors that seem to characterize human decision making produced the following list. (Nothing is implied by the order of items in the list.)

- Affirming the consequent. Applies to implicative statements. Tendency to assume that "if X, then Y" implies "if Y, then X."
- Failure to use rarity principle in inductive reasoning, i.e., given "if X, then Y," the rarer X is, the better an indicant of X is Y.
- Place-keeping failures. This is when your finger slips out of a book.
- Suboptimal use of information re the reliability of data.
- Lack of mapping between probabilistic terminology and conversational terminology.
- Biasing of frequency estimates in accordance with availability of exemplars.
- Gambler's fallacy.
- Compartmentalization of data from disparate sources.
- Preference for single orderings--tendency to interpret comparative data as transitive.
- Overconfidence in one's opinions.
- Hindsight or retrospective biases in evaluation and analysis.
- Misunderstanding of logical operators, Boolean operators, etc.
- Tendency to search for data that affirm working hypothesis, rather than making critical test of hypothesis.

- Misunderstanding nature of expertise.
- Effects of earlier commitment on subsequent information seeking and interpretation.
- Ignoring base-rate information.
- Illusory correlations.
- Preference for redundant information, over independent information.
- Confusion of correlation with causation.
- Premature proposal of solutions.
- Effect of winner-loser status on quality of decision.
- Tendency towards inertia or status quo.
- Failure to perceive problem isomorphisms, analogous situations.
- Failure to perceive differences between situations that are isomorphic in some respects but not others.
- Too much credence in small-sample statistics.
- Risky-shift tendency to choose riskier alternatives in group setting than alone.
- Problems inherent in multiperson filter, e.g., premature filtering, thresholding, distortions.
- Reluctance to be bearer of bad tidings--especially to boss.
- Overcompensation for companions.
- Bandwagon effect.
- Binary fallacy. Failure to recognize intermediate possibilities.
- Pluralistic ignorance. Failure to recognize ignorance when widely shared: "200 million people can't be wrong."
- Difficulty of integrating or assimilating multidimensional information.

33. Suggestions for future research included the following:

a. Development of better methods for doing sensitivity analyses to evaluate the consequences of various types of decision errors.

b. Experimental confirmation of some of the "intuitively known facts" regarding decision-making capabilities and limitations of human beings.

c. Intensive studies of "decision-making experts." What is it that characterizes proficient decision makers (as judged by their peers) from ineffective ones? Storage of massive amounts of knowledge that is relevant to the decision problem? The application of effective procedures for analyzing and solving decision problems?

d. More intensive investigations of how people structure problems and decision situations, including how they generate hypotheses. The emphasis in the past seems to have been on analytic skills. There is need to pay more attention to creativity and synthesizing abilities.

e. Methods for training of decision makers should be investigated. There is very little in the literature concerning how to train people in decision-making skills in such a way that what they learn will transfer from one decision-making context to another. Some work has been done on debiasing techniques, calculated to teach people to compensate for some of the systematic errors that have been characteristic of decision makers in certain probabilistic decision situations.

It is not really known at what level of generality decision-making skills can be taught. The question deserves more attention from investigators than it has received.

f. There is a need for better conceptual frameworks in terms of which to describe goals and subgoals of complex systems and system components.

g. There is a need for more adequate theory to guide the allocation of decision-making and problem-solving functions to men and machines in man-computer systems.

h. Given the continually decreasing cost of computer memory, it seems certain that computers will be used more and more to store massive amounts of data, to support various C^3 operations. It will, therefore, become increasingly important to find effective ways of filtering, organizing, searching and purging very large data bases. The storage of large amounts of information will prove to be an encumbrance and an embarrassment unless more effective procedures are developed for utilizing the information in such data bases.

i. Resource allocation is an example of a generic problem that all commanders face. Consequently, a type of decision aid that could have impact at many points within C^3 systems would be a resource-allocation aid.

SECTION VII

NOTES FROM WORKSHOP 6

MAN-COMPUTER DIALOGUE DEVELOPMENT

6, 7 October 1976

BBN, Cambridge, Ma.

C^3
Workshop #6
6, 7 October 1976
BBN, Cambridge, Mass.

List of Attendees	Affiliation
Dr. Richard Bolt	M.I.T.
Dr. Alphonse Chapanis	Johns Hopkins
Dr. Ira Goldstein	M.I.T.
Dr. John Gould	IBM
Dr. James Miller	Science Applications, Inc.
Dr. Nick Negreponte	M.I.T.
Dr. Rudy Ramsey	Science Applications, Inc.
Dr. Sidney Smith	Mitre Corp.
Dr. Perry Thorndike	Rand Corp.
Dr. Keith Wescourt	Stanford University
Dr. Douwe Yntema	Harvard University
Dr. Marilyn Adams	BBN, Cambridge
Dr. John Brown	BBN, Cambridge
Dr. Collins	BBN, Cambridge
Dr. Carl Feehrer	BBN, Cambridge
Mr. Austin Henderson	BBN, Cambridge
Dr. Duncan Miller	BBN, Cambridge
Dr. Raymond Nickerson	BBN, Cambridge
Dr. Richard Pew	BBN, Cambridge
Mr. Oliver Selfridge	BBN, Cambridge
Dr. Albert Stevens	BBN, Cambridge

MEMORANDUM

To: Invitees to Workshop No. 6: Man-Computer Dialogue Development

From: R. W. Pew, Bolt Beranek and Newman Inc. RWPew

Subject: WORKSHOP

Date: 16 September 1976

We are engaged in a project for the Human Resources Office of the Defense Advanced Research Projects Agency on Human Factors in Command, Control and Communication (C^3) systems. A major objective of the project is the development of a plan for a program of research on this topic. It is not our purpose to design C^3 systems, but, rather, to identify researchable human factors problems relating to the performance of such systems.

As one means to this end, we are convening a series of workshops to bring together small groups of appropriate individuals to discuss various aspects of the problem. One such meeting is scheduled to be held in Cambridge, Mass. (BBN office at 10 Moulton Street) on October 6 and 7. The purpose of this meeting will be to discuss man-computer dialogue development in relationship to C^3 systems. In particular, what we hope to accomplish is the articulation of some significant researchable problems pertaining to this topic in C^3 contexts.

This memo is a follow-up to the invitation you recently received by phone to participate in this meeting. We are very pleased that you have agreed to meet with us and look forward to seeing you on the 6th. We have limited the number of participants to not more than 20 so we can maintain a lively discussion in an informal atmosphere.

What we want at the meeting is a far-ranging discussion of issues that participants consider to be germane to the general topic. To provide a context and some points of departure, we have drafted a brief background paper on C^3 systems, and prepared a list of questions that are representative of those that we might discuss at the meeting. Both of these documents are enclosed.

We plan to devote the first morning, or whatever portion of it is required, to brief (10-15 minute) presentations by participants. While the invitation is not contingent on your agreeing to make such a presentation, we would appreciate it very much if you would be willing to take this time to give your perspective on the general problem. If you wish, you might use the time to introduce possible topics that you feel are especially important to explore during the meeting.

The meeting will start at 9:30 a.m., Wednesday, October 6, and end early in the afternoon of October 7. If you would like us to make hotel reservations for you, please indicate that on the enclosed self-addressed postcard (specify the night or nights), and return it to us as soon as possible. Enclosed is a map of the area to help you find your way to BBN.

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Probably the easiest way to get here from the airport is to take a cab. If the driver does not know where Moulton Street is, tell him it is in the Fresh Pond area of Cambridge. We will, of course, reimburse you for reasonable expenses incurred as a result of your participation (travel, meals, lodging) and can offer you an honorarium of $150 per day. Perhaps the more significant motivation for participation is the chance to help shape a new DARPA program that is likely to provide research opportunities for human factors specialists in the future.

See you on the 6th!

Enclosures:

Background Notes
List of Questions
Self-Addressed Stamped Postcard
Map

RWP/met

WORKSHOP NO. 6: MAN-COMPUTER DIALOGUE DEVELOPMENT

October 6 and 7, 1976

We would like to focus this meeting on researchable issues in the development of man-computer dialogue techniques and methods that are relevant to application to future C^3 systems. Since there is so much lore and so little data, it will take a concerted effort to focus on issues that are amenable to research as opposed to discussing the relative advantages and disadvantages of particular techniques. The following incomplete set of questions is designed to stimulate such a discussion. Please feel free to add to this list.

I. METHODOLOGY

1. Given that one has defined an application, what methods may be employed to systematically select and design the most appropriate techniques or procedures for man-computer interaction?

2. What role should task analysis play or user requirements analysis play in defining dialogue specifications?

3. What role should protocol analysis play in defining dialogue specifications?

4. Is it possible to simulate alternative dialogue forms prior to completion of applications software?

5. What role, if any, should formal experiments play in the development of dialogue specifications?

6. Is it possible to conduct formal experiments in a way that the results will lead to generic principles of dialogue specification?

7. At what stage of system development is it most appropriate to initiate the development of dialogue specification.

II. TAXONOMY OF DIALOGUE NEEDS

1. Is it possible to formulate a mutually exclusive and exhaustive set of generic classes of requirements such as numerical data entry, inquiry of data base and so forth having implications for design of system "front-ends"?

2. If we had such a taxonomy would it be useful?

III. MODELS OF THE COMPUTER USER

It is often asserted that dialogue specification would be greatly facilitated if we could develop a conceptual model of the user and the way he "thinks," about the problem to be solved.

1. Is it realistic to think that such a model might be derived either in general or in specific applications?

2. If only specific applications can be considered, what are the conditions required that might make such models realizable?

3. What form might such models take?

4. What methods might be employed to develop such models?

IV. DIALOGUE COST-EFFECTIVENESS

The software required to implement various dialogue forms may vary from simple, prestored, branching structures to the most sophisticated artificial intelligence systems. The level of sophistication has an impact on both development cost and time and on operating demands on the central processing system. Methods are needed for evaluating the impact of building front-end software at varying levels of sophistication in terms of its potential payoff for overall system effectiveness.

1. What measures might be proposed to evaluate the economic impact of introducing alternative dialogue techniques.

2. What measures might be developed to assess the complexity of software required to implement a particular dialogue concept.

3. How are "ease of use" and data-entry reliability evaluated in terms of the impact of introducing alternative levels of sophistication in front-end design?

V. IMPACT OF USER CHARACTERISTICS

We say that knowledge of the characteristics of the user population are essential prerequisite to effective dialogue design.

1. What characteristics of users do we believe are important?
2. How do we assess or measure the levels along the dimensions we believe are important?
3. How do we translate specifications of user characteristics into usable constraints on dialogue generation?

V. ALTERNATIVE DIALOGUE IMPLEMENTATIONS

The following list of alternative dialogue forms is suggestive of the range of techniques available.

1. Menu
2. Form-filling frame
3. Question and answer
4. Prompted input
5. Limited syntax command language
6. Typed natural language
7. Real-time interactive speech
8. Constrained natural language, either speech or typed
9. Interactive graphics

One can think of many possible issues concerning the conditions under which one or more of these techniques is particularly useful. Among them are:

1. How does the Display device, for example printing terminal vs. CRT, impact on the choice of technique?
2. Dialogue control and front end intelligence may reside in the terminal, in a communications concentrator or in a host computer. How does this location impact on the choice of dialogue forms?
3. If control is remote what is the impact of communication's bandwidth on choice of dialogue implementation.
4. What is the impact of potential system response time and/or its variability on choice of dialogue techniques.
5. What are the implications if real-time speech input is to be integrated with other modes of interaction?
6. Is it possible to teach users to operate with a constrained vocabulary? If so, what are the limits in practical applications and what are the training implications.

7. Is it possible for a user to learn to use a restricted set of grammatical syntax with or without constraints imposed on vocabulary. We know they can use a fixed syntax and unconstrained syntax. The interesting cases lie in between.

8. What does the discipline of psycholinguistics have to contribute to the design of command language syntax?

MEMORANDUM

To: Conference Participants

From: R. W. Pew

Subject: Notes from ARPA Workshop No. 6 on Man-Computer Dialogue Development

Date: 7 January 1977

In connection with the ARPA sponsored BBN program concerning Human Factors and Command,Control and Communications Systems, a workshop was held on October 6 and 7 under the general title of Man-Computer Dialogue Development. The workshop brought together computer scientists and psychologists interested in issues relating to the design of friendly interactive computer systems. No attempts had been made to impose an organization or apply any judgment to the topics that had been discussed. These notes simply present the ideas in roughly the same order as they were presented at the meeting.

NOTES from October 6 and 7 Workshop Concerning Man-Computer Dialogue Development.

The RITA System

The session began with a description of the Rand Interactive Terminal Agent System (RITA). RITA is intended to be a component of an intelligent terminal development. It is an information system in which "agents" act on behalf of the user to carry out relatively routine and prespecified tasks. It is most useful in situations that are in part event-driven, that is, situations in which the need for activity can be predicted relatively well given the development of certain contingencies. Thus far, it has been applied to a problem in air search and rescue and to modelling terrorists' behavior.

For example, in search and rescue activities, the user might ask for the status of the aircraft in the vicinity of an accident. RITA would then activate an agent to: (1) define those locations in the immediate vicinity of the accident, (2) send messages to those sites to inquire of available aircraft status, (3) receive messages back from those sites concerning aircraft status, and, (4) assemble those reports into a single report communicating aircraft status back to the user. The system provides an explanatory capability because it can report its own logic chain leading to the output of a particular response. A further important feature of the system is its ability to accept new knowledge incrementally and to introduce new rule sets. A question was raised, however, concerning exactly how easy it would be for a novice user to accomplish such changes.

In the context of the discussion of the use of a RITA-like system to systematically reduce the message processing workload that is presented for a commander to review, the question was raised as to the need to define or impute a purpose to the user. That is, in choosing what messages he wishes to read, the designer must relate that set to the purpose for which he wants to read them, and those purposes are not static. Thus it would be difficult to build such a system to meet changing needs realistically.

The RITA system appears also to provide a rich environment in which to examine the modes in which user requests for action can be most effectively communicated to a computer.

Variable Influencing Design

A discussion was held concerning some of the important dependent and independent variables of interest to individuals attempting to design effective man-computer dialogues. The dependent variables include:

1. Amount of training.
2. Range and type of users.
3. Time to perform tasks.
4. Error tolerance.
5. User's preference.
6. Creativeness of solution.

Included in the list of independent variables were:

1. Spoken vs. typed commands.
2. Formal command language organization.
3. Type of terminal.
4. Precision of information presented.
5. Natural language vs. formal language; written vs. spoken.

This outline led to a discussion of the problem of errors. It was suggested that we need to build a taxonomy of types of errors and that we need a methodology for locating in advance potential, error prone circumstances in a dialogue. We do not have good theories of the deep structure of errors that permit generalizations from one application to another.

Research and Application Methodology

The question of methodology breaks into two issues. The first question concerns how to do research that has the potential to impact on future system designs. The second concerns the methodology for developing actual systems. With respect to the first question, one could consider controlled studies in a laboratory or naturalistic observations in a field setting. It is likely that there are a continuum of methods between these two extremes. It was observed that there are only a very few laboratory studies to date that have been conducted in a mode

that generalizes to future systems design. It is not clear that we really know how to do laboratory studies of this kind.

The two best examples of laboratory studies are of those of Yntema and his colleagues concerning the effects of system response time on performance and Chapanis' studies of interactive communication between pairs of individuals and among small groups. Chapanis described his experiments involving two-person problem solving teams in which one individual was given a specific problem to solve and the second individual was given the information sources needed to solve it. The two must work together to produce a solution. He has studied a variety of communication modes ranging from face-to-face with full speech capabilities to a remotely-linked interactive typewriter mode. He examined the activities that people undertake in solving such problems, the variables associated with their communication, the quality of their solutions, the time required for solutions, and their attitude about communications. The three most important results were: (1) while 10 to 15 times as many words are used in a speech communication mode, the problems were solved roughly twice as fast in the speech modes than in the written modes; (2) both spoken and written dialogue bore virtually no relationship to formal English grammar and structure -- the remarkable thing is that people can, in fact, read through the distortions of the English language that are introduced in communications of this type; and (3) in experiments with restricted vocabularly, it was found that the time to solve the problem did not change even when the vocabulary was restricted to 300 words.

With respect to the methodologies for systems design, four approaches were discussed: protocol analysis, paper and pencil simulations, computer-implemented simulations, and "software overkill."

Protocol analysis involves in-depth interviews with representatives of a user population who are fully knowledgeable with respect to the way in which the operation could be computer-aided. The first goal of protocol analyses is to identify the collection of strategies that a user can employ to make inferences from available information. One attempts to abstract the underlying structure of the problem from the interviews. Protocol analyses have been applied over a range of levels of specificity from generic analyses of human inference structures to studies of the goal structure and inquiry patterns associated with a particular task. It was pointed out that if one is working in a practical context, it is very difficult to conduct a protocol interview without leading the user to report what you as the interviewer expect to hear.

Paper and pencil simulation is a natural extension of protocol analyses. In this case an inference structure and dialogue protocol are developed and the user is presented with a series of frames representing the conduct of an interactive session with the computer. One can solicit information concerning vocabularly, conceptual understanding, and the appropriateness of the branching structures, but, since the interaction does not occur in real time, it is difficult to use it for evaluating many of the desirable characteristics of an interactive dialogue that result from its temporal coherence.

The next level of sophistication in interactive dialogue evaluation would provide a computer implementation of a prestored dialogue structure and sample frames as they would appear to the user. It is not necessary in this simulation to represent the underlying processing structures, only the frames as they would appear to a user. Prestored scenarios would be introduced that allow a user to progress through a well-specified activity. The simulation developer would anticipate the major branches and the kinds of data that would be needed for a user interaction. This level of simulation permits evaluation of the real-time interactive features of the dialogue, but again, it is limited to the designer's conception of how the system should work. It requires iterative application of the method to evolve new strategies of interaction. The assembled group could think of no specific examples where this had been done but it was argued that it would be very feasible to develop a general-purpose dialogue simulation language to make it easy to implement alternative sequences in this way.

The final proposal for the development of computer-based user aids for novel applications involves what John Brown refers to as "hardware and software overkill." As a developmental stage in systems design, it was argued that a very general purpose system should be built that would enable very easy implementation of many alternative configurations. With such a system it would be possible to put together alternatives in a few days that normally would take several weeks or months. While the initial investment in such a system would be great, it would make it possible to explore alternative interactive modes, to examine the evolution of user response and to genuinely adapt the system as new patterns of user interaction emerge.

As a footnote to this methodological discussion the human factors practictioners in the group pointed out that simply exploiting the technology for developing user requirements through task analysis and protocol analysis and proceeding to write a user's manual prior to system implementation could go a long way toward creating a friendly system with no further technological developments necessary.

Role of Artificial Intelligence

Another major theme of the workshop concerned the role of artificial intelligence in the development of "friendly" systems. Ira Goldstein presented an articulate summary of his work on knowledge support systems, including an office planning assistant, and an intelligent advisor for the WUMPUS Game. He argued that an intelligent assistant for either case implies a model of user knowledge and a model of user interactive strategies. In any system which is going to provide intelligent advice, it is important not only to provide a model for the decision process but also an articulate "expert" that can explain the rationale underlying the decision algorithms invoked. Similarly the model for user interactive strategies also implies an articulate "tutor" that can rationalize the strategies that have been implemented. Effective models of user knowledge and interactive strategies will push the frontiers of artificial intelligence. The intelligent advisor to WUMPUS represents a level of system complexity for which such a development seems feasible at the present time. It could serve as a very effective laboratory environment in which to explore human factors' questions concerning the information that is needed, and the ways in which that information should be structured and presented to human users.

The discussion went on to describe some of the properties of useful user models to imbed in a friendly system. If we could achieve a genuine understanding of the user's knowledge base and his interactive strategies, several modes of assistance to users would be possible. It would be feasible to offer advice concerning alternative actions to take and to provide the rationale from why those are appropriate actions. It might be possible to begin to go beyond simple feedback reporting that an utterance was not understood and provide feedback about what the user could have said that would have been understood. It would be possible to decide when the user needs tutorial assistance and when it is superfluous.

Implementing these ideas requires development of the knowledge-base concepts underlying them beyond the point they are currently developed. It requires a theory of human inference. It requires a theory of hints that elaborates how much knowledge is necessary before a hint will be useful to an individual. It requires a better understanding of the use of contextual information. The art of communication is based on the fact that we understand each other's world view, but there are boundaries on where context is helpful and the circumstances under which it is a burden. People are largely unaware of their own ambiguities. It requires the development of more sophisticated grammars functioning at both semantic and pragmatic levels.

We need a better understanding of ways to represent human goals. Goal structures change within the conduct of particular tasks as well as across tasks. We cannot treat a single utility function as an overriding one in any particular context. Goals provide one kind of context and, as certain kinds of knowledge become available, the context in which those goals were relevant tend to shift, leading to a changing goal hierarchy. Analysis of goal structures could lead to broader examination of the relation of between human motivation and system design.

The development of "understanding" depends on having well-defined and limited domain boundaries. Successful systems such as SOPHIE and WUMPUS depend on the fact that the domain in which inferences must be made can be well-defined and circumscribed. Where we have difficulty is where we attack problems of inference for which such boundaries are difficult to conceptualize. The limits are not vocabulary or grammar limits per se, but rather limits on the domain of discourse.

A further underlying theme was the role and usefulness of natural language communication in man-computer dialogues. Several participants supported the belief that the goal of natural language communications with computers is an essential component of friendly systems. Setting aside, for the moment, the fact that the full richness of natural language requires a model of the user's world view, these proponents reject the argument that natural language interaction is necessarily inefficient and verbose. They suggest that even where concise and brief language is required, the model of natural language is still the appropriate one. As one data point in support of this view it was pointed out that the Lakewood, Colorado police force information system abandoned the use of artificial language in favor of natural language with very great improvement in the acceptance of the system.

The alternative view is that the intrinsic ambiguities in human use of natural language particularly spoken language, as well as its inherent verbosity make it undesirable for interaction with unforgiving computer systems. Instead we should be seeking to build formal command languages that take account of human stylistic variables and that impose an easy-to-use formal structure on inquiries and other communications. This approach seems particularly appropriate for the class of users for whom the system does not represent a discretionary tool but rather an integral part of their daily activities.

Graphical Display Capabilities

Negreponte and Bolt described their work on novel graphical display environments, and illustrated it with a videotape demonstration. They think in terms of spatial data management as opposed to symbolic data management and regard a display surface as simply a means for presenting one component of a virtual array of possible displays. They wish to consider the possibility of an entire room serving as a medium for display interaction.

On the input side they consider light pens and keyboards as too restrictive and are experimenting with touch sensitive surfaces that would make possible the use of gestures as a mode of communication. They are working toward a taxonomy of useful gestures and think in terms of a language built up out of a vocabulary and syntax of gestures.

Touching again on a methodological point, it was argued strongly that developments such as these highlight the importance of not conducting formal evaluations of the capability of specific systems but rather that design must proceed in evolutionary steps because the understanding of the new way in which systems may be used is a discovery process that is difficult to anticipate in advance. The use of raster scan TV technology to produce relatively inexpensive color displays and to make it possible to produce camera-ready copy directly from the display were cited as examples of developments for which it would be hard to anticipate the advantages and uses.

Issues in the Command and Control Context

James Miller presented a perspective on the command and control context in which interactive systems might be used. He noted that commanders exhibit considerable reluctance to use a machine-based decision aids. Some will even refuse to log on to such systems. We need to investigate the effectiveness of system

personalization and to demonstrate the ability to augment the capabilities of a commander in order to produce acceptable systems. A commander probably needs a large screen display capability and a conferencing capability. A researchable issue concerns the need for color displays at this level.

He noted that the command and control environment is time sensitive. At the highest level of WWMCCS we might have thirty minutes warning; once an enemy launch has been detected, if it is an airborne launch, there may be only two minutes of time in which to act. If it is a submarine launch, then there may be fifteen minutes remaining to act.

There is some interest in considering distributed data bases for command and control tasks; however, there is no research concerning the advantages or disadvantages to the user resulting from distributed data bases. There is also a need for the development of standard measures of command and control systems effectiveness that could be applied to evaluate the advantages of computer augmentation.

The introduction of data bases that are accessible at different levels in the command raises a further question concerning the capability of a commander to second guess the activities and analyses of lower echelons.

The ensuing discussion highlighted the great need for more global studies of the organizational impact of imposing computer-assisted decision aids and information systems in a military context.