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NORTH ATLANTIC TREATY ORGANIZATION

RESEARCH AND TECHNOLOGY ORGANIZATION

BP 25, 7 RUE ANCELLE, F-92201 NEUILLY-SUR-SEINE CEDEX, FRANCE

RTO MEETING PROCEEDINGS 57

Usability of Information in Battle Management Operations

(l'Exploitation de l'information dans les opérations de gestion du champ de bataille)

Papers presented at the RTO Human Factors and Medicine Panel (HFM) Symposium held in Oslo, Norway, 10-13 April 2000.

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Abstract
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Information systems	Comprehension	Decision support systems
Aerial warfare	Culture (social sciences)	Knowledge management
Mission effectiveness	Design	Teams (personnel)
Situational awareness	Experimentation	

14. Abstract

On 10-13 April 2000, NATO, Partnership for Peace, and Non-NATO nationals from 21 countries met in Oslo, Norway to discuss the perceptual, cognitive, social, and contextual factors and considerations that will impact the usefulness and usability of information and information technologies in battle management operations. Sponsored by the Human Factors and Medicine Panel of the North Atlantic Treaty Organization's Research and Technology Organization, the symposium participants discussed the problem, research approaches and techniques for improving team performance and enhancing effectiveness, concepts for battlespace visualization and decision support, and the integration of collaborative battle management systems. The symposium included four Keynote Addresses and sessions on:

- Operational Problems in Battlespace Management;
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The Research and Technology Organization (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote cooperative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective coordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also coordinates RTO's cooperation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of initial cooperation.

The total spectrum of R&T activities is covered by 7 Panels, dealing with:

- SAS Studies, Analysis and Simulation
- SCI Systems Concepts and Integration
- SET Sensors and Electronics Technology
- IST Information Systems Technology
- AVT Applied Vehicle Technology
- HFM Human Factors and Medicine
- MSG Modelling and Simulation

These Panels are made up of national representatives as well as generally recognised 'world class' scientists. The Panels also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier cooperation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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Usability of Information in Battle Management Operations

(RTO MP-57)

Executive Summary

On 10-13 April 2000, NATO, Partnership for Peace, and Non-NATO nationals from 21 countries met in Oslo, Norway to discuss the perceptual, cognitive, social, and contextual factors and considerations that will impact the usefulness and usability of information and information technologies in battle management operations. This symposium was part of the activities of the Human Factors and Medicine Panel of the North Atlantic Treaty Organization's Research and Technology Organization.

Command and control operations are becoming increasingly more complex. At the same time, information technology is evolving at an unprecedented pace yielding impressive capabilities but also helping to place a tremendous informational and perceptual burden on commanders, controllers, and warfighters. Past history suggests that when system developers fail to consider the mutual effects of cognitive, informational, social, and contextual factors, there is an increased probability of incidents, accidents, and failures. By contrast, with new collaboration and visualization technologies, it is possible to increase the perceptual, cognitive, and information utility of command and control systems.

To achieve this improved utility in battle management operations, it is imperative that command and control system designers interweave collaboration and visualization technologies with a deep understanding of how humans perceive and process information, make decisions, and interact with computer interfaces, and how users function in individual and collaborative environments. This combination of knowledge of human capabilities with technology advances offers the promise of providing mission- and task-critical information that is easily used by battlespace managers and warfighters.

l’Exploitation de l’information dans les opérations de gestion du champ de bataille

(RTO MP-57)

Synthèse

Des membres de l’OTAN, des représentants des pays du Partenariat pour la Paix et des représentants de 21 pays non-membres de l’OTAN se sont réunis à Oslo du 10 au 13 avril 2000 pour discuter des facteurs cognitifs, perceptifs, sociaux et conjoncturels qui auront un impact sur l’intérêt et l’exploitabilité des informations et des technologies de l’information dans le domaine du commandement et contrôle du champ de bataille. Ce symposium faisait partie des activités de la Commission des Facteurs humains et de la Médecine de l’Organisation pour la recherche et la technologie de l’OTAN (RTO/HFM).

Les opérations de commandement et contrôle deviennent de plus en plus complexes. Parallèlement, les technologies de l’information évoluent à une vitesse sans précédent, offrant certes des capacités impressionnantes, mais représentant aussi une charge informationnelle et perceptive considérable pour les chefs militaires, les contrôleurs et les combattants. L’expérience du passé indique que pour les concepteurs de systèmes, le fait de ne pas prendre en compte les effets combinés des différents facteurs cognitifs, informationnels, sociaux et conjoncturels équivaut à augmenter la probabilité d’incidents, d’accidents et de pannes. En revanche, de nouvelles technologies de coopération et de visualisation permettent d’accroître l’utilité perceptive, cognitive et informationnelle des systèmes de commandement et contrôle.

Afin d’assurer une meilleure efficacité dans la gestion du champ de bataille, il est indispensable d’intégrer dans les opérations de commandement et contrôle et dans les recherches technologiques, une compréhension approfondie des capacités cognitives et perceptives humaines (c’est à dire la manière dont les êtres humains perçoivent et traitent l’information, prennent des décisions, et interagissent avec les interfaces informatiques) ainsi que la connaissance du comportement humain dans des environnements individuels et coopératifs. Cette combinaison des capacités humaines et des avancées technologiques permet d’espérer disposer d’informations décisives pour la mission sous une forme facilement exploitable par les gestionnaires du champ de bataille et les combattants.

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† Paper not available at time of printing.

† Paper not available at time of printing.

Human Factors and Medicine Panel

Chairman:

Dr M.C. WALKER
Director, Centre for Human Sciences
DERA
F138 Building - Room 204
Farnborough, Hants GU14 0LX
United Kingdom

Co-Chairman:

Col. W.C.M. TIELEMANS, MD
RNLAF/SGO
P.O. Box 20703
Binckhorstlaan, 135
2500 ES The Hague
The Netherlands

PROGRAMME COMMITTEE

Chairmen

Dr Ken BOFF
Human Effectiveness Directorate
Air Force Research Laboratory (AFRL/HE)
2610 Seventh Street
Wright-Patterson AFB
OH 45433-7901, USA
Tel: +1 937 255 6327 ext. 246
Fax: +1 937 656 7617
E-mail: ken.boff@he.wpafb.af.mil

Dr Nahum. D. GERSHON
The MITRE Corporation
1820 Dolley Madison Blvd
McLean, Va 22102-3481, USA
Tel: +1 703 883 7518
Fax: +1 703 883 3615
E-mail: gershon@mitre.org

Members

Ms Sharon MCFADDEN
DCIEM
P O Box 2000
1133 Sheppard Avenue West
North York, Ontario M3M 3B9
Canada
Tel: +1 416 635 2189
Fax: +1 416 635 2011
E-mail: smcfadden@dciem.dnd.ca

Méd. en Chef J.Y. GRAU
IMASSA/CERMA
BP 73
91223 Brétigny sur Orge Cedex
France
Tel: +33 (0)1 69 88 33 72
Fax: +33 (0)1 69 88 33 02
E-mail: jygrau@imassa.fr

Dr Alain LEGER
Sextant Avionique
Rue Toussaint Catros
BP 91
33166 Saint Médard en Jalles, Cedex
France
Tel: +33 (0)5 56 13 51 68
Fax: +33 (0)5 56 13 50 37
E-mail:
alain.leger@sextant.thomson.fr

Prof. Dr B. DÖRING
Forschungsgesellschaft fur Angewandte Naturwissenschaften (FGAN/EFM)
Neuenahrerstr. 20
D-53343 Wachtberg-Werthhoven
Germany
Tel: +49 228 943 54 60
Fax: +49 228 943 55 08
E-mail: doering@fgan.de

Dr Erik FOSSE
Head of Department
Rikshospitalet
Intervensjonssenteret
N-0027 Oslo, Norway
Tel: +47 22 86 84 86
Fax: +47 22 86 84 91
E-mail: erik.fosse@klinmed.uio.no

Prof. Dr Ir. H. SCHUFFEL
TNO Technische Menskunde
P.O. Box 23, Kampweg 5
3769 ZG Soesterberg
The Netherlands
Tel: +31 346 356 315
Fax: +31 346 353 977
E-mail: schuffel@tm.tno.nl

Prof. Kemal SAVASAN
Head of Department Aerospace Medicine
Gulhane Askeri Tip Akademisi
Hava-Uzay Hekimligi ABD
Baskanligi
Etlik – Ankara, Turkey
Tel: +90 312 321 9625
Fax: +90 312 323 2480
E-mail: mksavasan@gata.edu.tr

Dr Graham ROOD
Manager Mission Management Dept.
Defence Research Agency
Room 204 – Bldg R177
Farnborough, Hants GU14 6TD
United Kingdom
Tel: +44 1252 393076
Fax: +44 1252 393091
E-mail: gmrood@dra.hmg.gb

Ms Jo DAVIES
ESE Associates Ltd.
15, Jesse Close
Yateley, Hants GU14 6AH
United Kingdom
Tel: +44 1252 876783
Fax: +44 1252 382060
E-mail: jo@ese-assoc.demon.co.uk

PANEL EXECUTIVE

Dr C. WIENTJES
BP 25 - 7, Rue Ancelle
92201 Neuilly-sur-Seine, France
Tel: +33 1 55 61 22 60
Fax: +33 1 55 61 22 99/98
E-mail: wientjesc@rta.nato.int or pelatd@rta.nato.int

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Technical Evaluation Report

Jeffrey I. Sands
The MITRE Corporation
1820 Dolley Madison Boulevard
McLean, Virginia 22012
United States of America

INTRODUCTION

On 10-13 April 2000, NATO, Partnership for Peace, and Non-NATO nationals from 21 countries met in Oslo, Norway to discuss the perceptual, cognitive, social, and contextual factors and considerations that will impact the usefulness and usability of information and information technologies in battle management operations. Sponsored by the Human Factors and Medicine Panel of the North Atlantic Treaty Organization's Research and Technology Organization, the symposium participants discussed the problem, research approaches and techniques for improving team performance and enhancing effectiveness, concepts for battlespace visualization and decision support, and the integration of collaborative battle management systems.

THEME / OVERVIEW

Command and control operations are becoming increasingly more complex. At the same time, information technology is evolving at an unprecedented pace, yielding impressive capabilities but also helping to place a tremendous informational and perceptual burden on commanders, controllers, and warfighters. Past history suggests that when system developers fail to consider the mutual effects of cognitive, informational, social, and contextual factors, there is an increased probability of incidents, accidents, and failures. By contrast, with new collaboration and visualization technologies, it should be possible to increase the perceptual, cognitive, and information utility of command and control systems.

Collaboration technologies enable people to share information, communicate, and coordinate across time and distance boundaries. They include asynchronous tools, real-time conferencing tools, and virtual collocation tools (often referred to as place-based collaboration environments). Visualization technologies can help humans perceive and process information. They include information visualization, graphic databases, multimedia, animation, video information storage and retrieval, etc. The promise of both sets of technologies is to improve our ability to collaborate, coordinate, share, and understand information to facilitate inter- and intra-organizational teams.

To achieve this improved utility in battle management operations, it is imperative that command and control system designers interweave collaboration and visualization technologies with a deep understanding of how humans perceive and process information, make decisions, and interact with computer interfaces, and how users function in individual and collaborative environments. This combination of knowledge of human capabilities with technology advances offers the promise of providing mission- and task-critical information that is easily used by battlespace managers and warfighters.

SYMPOSIUM PROGRAM

The Symposium, chaired by Dr. K. Boff and Dr. N. Gershon from the USA, consisted of an Opening Session, five Scientific Sessions, four Keynote Addresses, 22 papers, a Capstone Panel, and an open discussion period. The final program was organized by Ms. J. Davies (UK), Dr. B. Döring (GE), Dr. E. Fosse (NO), Dr. N. Gershon (USA), Dr. J. Grau (FR), Dr. A. Léger (FR), Dr. G. Rood (UK), Dr. K. Savasan (TU), and Dr. H. Schuffel (NE).

After welcoming addresses by Gen. S. Frisyold, Chief of Defense, Norway, and Maj. Gen. L. Rosen, Director General, Joint Medical Services, Norway, the **Opening Session** concluded with a Keynote Address (I) by BG K. Alexander (USA).

Dr. G. Rood (UK) chaired **Session I**, *Operational Problems in Battlespace Management*, featuring a Keynote Address (II) by Lt. Col. G. Pugh (UK).

Session II, *Research Approaches*, was conducted in two parts: Ms. J. Davies (UK) and Dr. B. Döring (GE) chaired Session IIa, *Team Performance*, and Dr. H. Schuffel (NE) and Dr. J. Grau (FR) chaired Session IIb, *Techniques for Enhancing Effectiveness*.

Dr. A. Léger (FR) and Dr. H. Schuffel (NE) chaired **Session III**, *Concepts for Battlespace Visualization and Decision Support*, featuring a Keynote Address (III) by Gén. L. Franquart (FR).

Dr. E. Fosse (NO) and Dr. N. Gershon (USA) chaired **Session IV**, *Decision Support Considerations*, featuring a Keynote Address (IV) by Prof. R. Værnes (NO).

Dr. Boff and Ms. S. McFadden (CA) chaired **Session V**, *Integration and Test of Battle Management Systems*. Dr. Gershon and Dr. Boff chaired the

Capstone Panel, and Dr. Gershon moderated an open discussion that took place earlier in the symposium.

TECHNICAL EVALUATION

I: The Problem

Problem Statement: Information rules the battlespace, Dr. Boff began the symposium. In the future, bits and bytes may be more important to determining the outcome of conflict than bombs and bullets. To do so, information must be both useful (able to promote advantage) and useable (accessed, interpreted, and applied for its purpose). The problem, according to BG Alexander *(Keynote I),* is how to visualize information to plan and fight—or to prevent—wars. Currently, we are unable to share and use information (national, theater, and tactical) efficiently, across echelons between services (Army, Navy, Air Force, Marine Corps), and amongst coalition partners. The problem derives from a number of causes, including: coalition limitations; formatting differences; security classification requirements; differing timeliness requirements for information; lack of adequate processing and collaboration capabilities; lack of independent systems. As a result, information hits different organizations at different times in different formats, resulting in disjointed, poorly coordinated and differing reactions to a common situation. This requires extensive and often inefficient manual efforts to ensure we are coordinated at every echelon.

The potential for misunderstanding is high when everyone's picture differs slightly. As Maj. Gen. Rosen noted in his welcoming address, preparedness and efficiency and the ability to work across borders are critical to success in dealing with human conflicts and disasters. In this modern world of technology, information, education, and training are all critical to enabling coalition forces to operate effectively, and as efficiently and safely as possible.

The challenge, Alexander suggests, is to get the right kind of information from the right sources to right people at the right time in the right form. This will require both pushing information to decision-makers in the field at various echelons, and enabling these decision-makers to pull the information that they deem relevant. To address this problem, we must develop a secure battle management information system and supporting infrastructure, and refine human-computer information procedures so as to manage and display information in ways that people can understand and take advantage of human intuition. This symposium focused on this latter issue. Specifically, *how can we better use collaboration and visualization technologies to enable individuals, teams, and organizations to operate more effectively?*

Problem Focus—Mastering Information: Command and control operations become increasingly more complex if not chaotic under real battle conditions. At the same time, the importance of psychosocial factors in battle management operations increases. Gen. Franquart *(Keynote III)* asks how we visualize information and mentally grasp it. His particular concern is situations of non-conventional war, inter-state versus intra-state conflict where the aim is not necessarily victory but political legitimacy by violence in all its varieties and intensities. In such conflicts, the commitment of force has a new purpose. Politically at the strategic level, force can be used to conciliate between opposing claims of legitimacy or create new legitimacy. The military objective is not to attack Clausewitzian centers of gravity, but to use force to "master violence," to assert control on key operational domains by countering the expressions, consequences, and especially the causes of violence. This requires information control—knowledge of violence perpetrators and organizations, and curbing their motivations. In terms of intelligence, we have to broaden our field of action to include the human and structural dimensions. We must look not only at the physical space occupied by a community or ethnic group (valley's, peaks, checkpoints), but also at the key points in human space (churches, markets) and the structural space that the community believes that it needs to flourish (production and communications facilities). The challenge is to develop visualization techniques that can help us comprehend the different types of networks that exist in physical, human, and structural space. But we must go beyond synthesis and judgement to "master the information" using human-centered processes in both the physical and psychological domains.

Problem Recognition—Information Overload: Many symposium participants noted the problem of information overload. The amount of informed use of information by battlefield commanders to make decisions is in practice quite small. With the advances of information technology, more information is presented to the decision-maker than can possibly be used. As Mr. Flemisch and Dr. Onken note *(Paper #23)*, more information and more functionality do not mean better usability or usefulness; on the contrary, it can cause problems for operator information processing. In practice, both tactical- and higher-level decision-makers increasingly place a premium on the ability to select out information from that presented to them by machines or command staff.

Mr. Alexander and Dr. Gärtner (Paper #12) note that in the field, operators can be overloaded by large amounts of changing information that cannot be kept up to date manually, especially in times of stress. At operations centers, computers process and visualize vast amounts of information that can still overload those that have to interact with the data. Moreover, staff interaction can often be limited. Humans will be influenced by the information available (technical) and perceivable (the real bottleneck). HF research must support decision making by enabling decision-makers to create a mental model of the battlefield situation for themselves, thereby helping to minimize their own information overload. This requires displaying huge amounts of complex data in an understandable and natural way.

According to Lt. Col. Pugh *(Keynote II),* we should seek not merely better information, but knowledge, what Dr. Cook *(Paper # 2)* describes as the fusion of information with prior knowledge that drives the process of information usage and allows for more effective action. Pugh suggests that at present, effective knowledge (that is, action based knowledge) can only really reside in humans. As Dr. Artman suggests *(Paper #2),* human beings have context sensitivity and flexibility that machines cannot rival. Hence, humans cannot be isolated, removed, or disengaged from the system.

Solution space must include Human Factors research: If we accept that knowledge superiority is the real required capability, Pugh argues, then it becomes apparent that the processes we develop to achieve that requirement must be human centered rather than technology centered. Thus, research into human factors (HF) will be a key factor in identifying and ensuring the eventual benefits of collaboration and visualization technology underpinning knowledge superiority.

Pugh argues that we need to develop a greater understanding of HF as people increasingly become integrated within the system. BG Alexander wants HF research to focus not on the ergonomics of that integration (such as the preferred slant of a keyboard), but on incorporating the physiology of how we think and learn (using as many of our senses as possible, including sound) into human-machine interface design. We must, as Dr. Cook put it, focus on the interface to allow "cavemen" to control the system. Pugh wants to strike a balance between HF and technology to ensure that technology designed to support command does not have the opposite effect (e.g., disrupting manual processes that otherwise work well). He urges exploring naturalistic decision-making to gain a better understanding of how individuals and teams make decisions in complex environments.

According to Prof.Værnes *(Keynote IV),* HF research to date has missed the big picture—decisions by decision-makers in real battlefield environments. Under conditions of severe stress (survival or death), decision-makers assess the situation unreliably, either coping or defensively altering their perception of the situation to enable action (or inaction), and cannot accurately project the consequences of their action. Decision-makers use mental rules of thumb—shortcuts that may prevent them from obtaining the most accurate information, and biases (e.g., defense mechanisms) that enable them to cope. We must therefore consider the perceptual, the cognitive, and the stress aspects of decision-making.

Pugh also believes HF research must explore the use of technology in the command estimate process to enable decision-makers to operate in a "knowledge-based" environment. It is not enough to focus just on the technology. HF research must play a role in developing not only the requirements for technology, but also the requirements for new organizational structures and the process of changing the command culture so as to get the users to use the technology that is developed. Success ultimately will derive from bringing technology into the mainstream of military business, using technology to help focus on creating what others call organizational knowledge, a human-created product of information, experiences, values, processes and cultures. Ultimately, Pugh cautions, we must recognize that the potential offered from enhanced and tailored information will never be fully realized.

In effect, Pugh is talking about using technology and HF research to promote knowledge management, a cultural, social, and human systems discipline as well as a technology-enabled program. Knowledge management activities are corporate strategies employed to foster innovation, knowledge transfer, improve business process, and enhanced organizational learning. There are activities critical to knowledge creation and innovation, such as knowledge exchange, capture, reuse, and internationalization. There are also elements that enable or influence knowledge-creation activities—for example, measurement (e.g., performance and effectiveness), policy, process, technology, and culture. The papers presented at the symposium examined both sets of activities—the processes of enabling or influencing knowledge-creation, as well as implementing knowledge-creation activities—for both individuals and teams, and of the system itself.

II. Research Enabling Knowledge Creation

"Enabling" visualization techniques: Col. Louisell (Paper #1) suggests that the emerging complexity of the international security environment requires a networked, multi-dimensional approach to understanding complex behaviors quickly. He argues that Systems Dynamics visualization models can help decision-makers leverage the effects of networked, information-based warfare. As Major R. King (the presenter of this paper) noted, Systems Dynamics models start with the assumption that there are no "new" situations; the challenge is to understand the emerging patters from past situations. Such models, King suggests, offer a quick solution, though not perhaps the perfect solution.

Dr. Sykora, Dr. Dworak, Mr. Michalek, and Mr. Novotny *(Paper #6)* use dynamic sociometry to analyze systems based on uncertain, ambiguous, and poorly defined elements. They focus on targeting decisions under NO PEACE / NO WAR conditions. In this method, the relations of elements (subjects, individuals, and groups) in a complex system are analyzed, and the results presented in a map, where the distances represent social relations (sympathetic or aversive) and altitudes correspond to high or low social positions. They conclude that dynamic sociometry is a potent and reliable tool for modeling complex situations. It can be used as a predictive tool in evaluating the impact of command decisions under extreme, poorly defined, and uncertain situations.

Dr. Van Delft and Dr. Passenier *(Paper # 14)* focus on the use of multiple views of the tactical situation to enhance situational awareness (see below) and improve situation assessment. Currently, tactical command information systems present information in a single, two-dimensional "bird's-eye view." New advances in graphics capabilities and display technology enable the application of three dimensional, stereoscopic displays. Their research suggests that higher information transfer rates (e.g., improved speed of detection for high-priority targets) can be obtained with parallel (related, but non-integrated) presentation of multiple views on the tactical situation (mixed 2D and 3D), with a decrease of user interaction with the system. In addition, using tactical objects in multiple views enables the user to modify and reconfigure the tactical workstation for effective supervision of and a rapid response to the tactical situation at hand. Stereoscopic technology also supports the visual separation of different information layers (e.g., mission and tactics) with each layer containing two-dimensional representations. As a result, many categories of information can be brought together in one integrated graphical representation of the environment and the tactical situation. The next challenge is to develop a tool for easy re-organization of information display when operators have to switch between tasks or when changes in the tactical situation take place. Van Delft and Passenier believe that developing and testing an object-oriented interface design enabling direct manipulation of tactical objects is the first step to meet this challenge.

Measuring Situation Awareness: Ms. Blackwell and Ms. Redden (Paper #7) examine the impact of situational awareness (SA) on unit effectiveness of dismounted infantrymen engaged in Military Operations in Urban Terrain (MOUT) missions. They define SA as the ability to: (1) quickly perceive and then discriminate between facets of the tactical environment; (2) accurately assess and reassess the where, when, and why of that environment; (3) know and understand the nature of the tactical situations; and (4) extrapolate near term courses of action based on this understanding. Their research team first used the Goal-Directed Knowledge Elicitation Technique to solicit situation-specific, field relevant mission needs from subject matter experts. The resultant mission needs then formed the basis of specific SA measures as a means to evaluate the effect of MOUT advanced concept technology (e.g., giving all soldiers a radio) on a unit's SA. The team then developed an approach for applying the SA measures to experimentation—the Questionnaire Assessment of Knowledge Technique—to quantify the impact of candidate technologies on individual and small unit operational effectiveness. They conclude that the freeze frame methodology (stopping the exercise at regular intervals to elicit participant responses) was particularly valuable in discriminating between baseline and technology conditions and tracking learning curves over time.

Follow the path well traveled: According to Dr. Kirchenbaum *(Paper #15),* we often develop battlespace management systems by decomposing the problem into many functions and tasks. Decomposition facilitates efficient engineering of the algorithms and programs, but the particular scheme used is not necessarily congruent with the way that the decision-maker solves the problem—evaluate the available information, predict the effects of various action options, and communicate the decision. Once the problem has been decomposed and then analyzed with the help of information management tools and decision aids, the decision-maker must put it back together in a mental information-fusion process, usually without the help of decision tools. Kirchenbaum proposes starting with knowledge of the decision-maker and then designing information management decision aids that support the knowledge schema and procedural structures already used by the expert decision-maker. That is, construct procedural paths through the task and the information that the decision-maker already uses, just as how natural paths occur because of repeated use by pedestrians. Kirchenbaum hypothesizes that this approach would lead to a more efficient decision performance—equal or better performance in a shorter time, with less effort. Her preliminary experimental results supported the hypothesis: organizing information based on procedural knowledge can facilitate performance of a complex, time-driven task; performance suffers in the absence of such a framework.

Interface design: Three major influences induce instability in command and control information systems over time: rapidly changing conditions regarding applied technology, changes in operational requirements, and the need to support different user profiles. As a consequence, a huge amount of information and knowledge in different data types has to be managed and processed in distributed communication networks. From the Human Factors point of view, the challenge is to provide users direct and easy access to the information that they actually need in operational situations. Cognitive automation and assistant systems offer promise to handling the overwhelming amount of information battle management systems will offer in the future.

To cope with information overload, Mr. Lenz and Dr. Ronken *(Paper #16)* investigated a prototype cognitive assistant system, the Crew Assistant Military Aircraft (CAMA), designed to enhance tactical transport crews' situation awareness and multifunctional task handling. CAMA "guides" rather than "directs" the crew in situation monitoring (perception and interpretation), diagnosis, decision-making and/or planning, and execution. The system independently assesses the goals of the crew and the tactical situation environment, detects possible conflicts of crew actions and current plans given changes in the environment, and initiates a natural, human-like communication to warn the crew of possible conflicts and propose corrective actions. They suggest that cognitive automation ("guiding" vice "directing") can improve productivity without loss of safety.

Mr. and Mrs. Kaster and Kaster *(Paper #21)* focus using "componentware" technology to create flexible system architectures (macro-view) with concrete military application, object-oriented software techniques (micro-view). They argue that by using this approach, designers can develop highly flexible systems that can be adapted easily to user needs and task requirements.

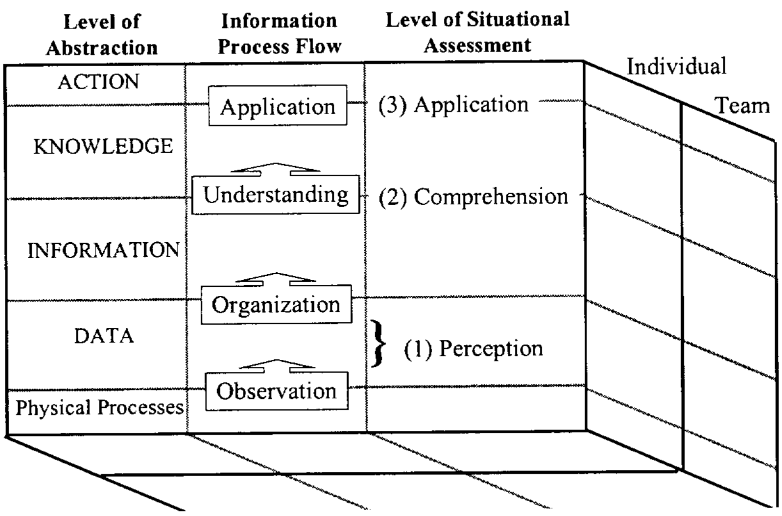
Drs. Young, Eggleston, and Whitaker *(Paper #19)* investigate what functionality should be provided to users of a future Joint Battlespace Infosphere that employs intelligent agents to seek, retrieve, and fuse information autonomously. The authors believe that new types of direct manipulation, work-centered interfaces are needed to reduce decision time and manning while maintaining positive control over the command and control system. With web-based interface techniques and agents, designers can transition the human computer interface layer from a mechanism to execute tasks into a decision-aid that supports cognitive information processing. This involves allocating 'off-task' system domain actions (data retrieval and fusion) to agents, leaving the 'on-task' activities for the on-screen display elements presented to the decision-makers.

Information presentation—testing assumptions: Usability issues are complex and require cognitive based investigations in multiple contexts and tasks. Gigley *(Paper #20)* reports on research employing interactive multimedia and user-centered design to enhance the decision-maker's ability to (1) find information, (2) query, refine, and process information, and (3) make and communicate decisions. The study reports that in some situations, animation as a language to enhance information transfer may not be a universal solution—some can learn from animation (especially when the student already understands and can mentally visualize the concept), but for others animation may hinder understanding. Other research suggests that the utility of 2-D and 3-D presentation formats vary with the task, but that 3-D presentation can often introduce ambiguity of understanding. Often, non-realistic 2D icons are the easiest to learn and to recognize, thereby enhancing situation awareness. Finally, other research suggests virtual environments have applicability to teams and integrated team tasks, but determining usability requires detailed evaluation. While costly, using the right level of evaluation at the right time in the design-usability process can lead to significant cost savings. The lesson from this research is that it is important to test our assumptions, which particular techniques will enhance or hinder information transfer, and which will not. Cost saved from the right kind of evaluation--doing the testing and evaluation up front to aid design for the task / application / population is not only cost effective, but also avoids training on workarounds or paying the cost of a single catastrophic failure.

III. Research Implementing Knowledge-Creation

Framework: Figure 1 shows the process of knowledge creation and effective use, *using just one among many ways to describe data, information, and knowledge and* their interrelationships.

Figure 1: Framework for "useful and useable" information processing



Working from the bottom, we (individuals and teams, together with our machines) obtain "data" by observing and measuring physical processes, and then processing those observations and measurements. To create "information," we index, organize, and store the data for subsequent retrieval. To obtain "knowledge," we must both understand and explain the information in context—that is, we must comprehend static and dynamic relationships between sets of data and information, and synthesize models to explain those relationships to decision-makers (i.e., ourselves, our colleagues, and others higher in the decision chain). Finally, we must apply knowledge to implement a plan or action effectively to achieve a desired goal or end state.

To make data and information useful and useable, decision-makers need to achieve and maintain Situational Awareness (SA) (see earlier definition). According to Værnes, there are three SA levels. Perception is the lowest level of SA, involving only the conscious knowledge that something is present in the environment. As shown in Figure 1, failures in perception correspond to failures of observation and organization. Comprehension (Level 2 SA) is the synthesis of disjointed perceptions to that understanding of the significance of the perceptions is present. Failures in comprehension correspond to failures in understanding. Projection (Level 3 SA) is the ability to project future courses of action based upon the understanding gained from Level 2 SA. Failures in projection correspond to failures in application. Værnes reports that failures in SA are the main cause of aviation accidents. Of the SA failures, three-quarters of accidents are due to level 1 failures, 20 percent by level 2, and only 4 percent level three. In other words, we have to work first on perception, then comprehension, and then projection.

Mr. Distelmaier, Mr. Dörfel, and Dr. Döring *(Paper #17)* present a slightly different concept structure of human problem-solving activities. They also divide complex tasks into three different performance phases—situation perception, situation assessment, and solution generation—that correspond roughly to the vertical processing activities depicted in Figure 1. Yet they add the complexity of differing cognitive task levels (skill-, rule-, and knowledge-based behavior) at each activity level, with applicable cognitive tasks varying depending on the situation encountered during each activity level. Hence, if operators encounter routine situations, they use skill-based information processing to perceive and recognize the situation and then take decisive action. If the available information does not directly lead to a reflexive situation/reaction routine, operators tend to interpret the available information using known heuristics and then generate solutions or appropriate courses of actions, if necessary. Finally, with ambiguous or uncertain information and unfamiliar or ill-structured situations, operators perform situation diagnosis using knowledge-based problem solving and evaluation techniques before proceeding to action planning and decision, as appropriate.

Cook suggests *(Paper #2)* that the process of knowledge development, creation, and maintenance itself drives the process of information usage. Was that process primarily individual- or team-based? Team knowledge management introduces additional complexities; even if knowledge is created, the system must be able to discern who should have the relevant information, in what form, and when. Hence, as shown in Figure 1, HF research must look at ways to enhance both individual and team SA performance.

Research into perception: Mr. Flemish and Dr. Onken *(Paper #23)* use a prototype eye measurement system to analyze visual attention of pilots, hypothesizing that missing visual attention is a strong indicator for mission situation awareness, itself a strong contributing factor for accidents.

Research into comprehension: Dr. Essens *(Paper #3)* examined individual and team performance in frigate operations centers. He discovered that individual and team processes compete with one another. Under conditions of load, demanding tasks (such as team processes) are dropped as individuals focus on tasks for which they are directly accountable. Since high workload conditions are normal in an operational command center, the question is how to manage that load more effectively. His research suggests that managing workload requires making organization processing capacity more flexible and adaptive, improving the quality of the team through training, and freeing team leaders from tasks of direct production in favor of management tasks.

Essens, Mr. Rasker and Dr. Post *(Paper #4)* describe a research framework for examining the effectiveness of command center teams. A command center, they note, is itself an information processing system. Each team member has a specific role, expertise, and information sources, but effective team action requires communication and coordination. They describe a framework of five research methods to investigate command center teams by examining different parts of the puzzle on how to optimize effective teamwork. *Modeling* implies breaking up a whole human-human-machine system into its essential elements. It is an analysis resulting in a clear description of the system as a system. Modeling addresses the question "What is the information flow in the command center?" *Observation* is needed to identify possible bottlenecks in command center. Through observation, we can gain insight into the composite set of factors that influence command center team effectiveness. *Experimentation* allows for systematic investigation of single factors--for example, the effect of intra-team feedback on developing shared mental models. With insight from these three techniques, *team design* (or redesign) can focus on improved effectiveness. For example, team design can focus on the best layout of the command center to encourage intra-team feedback of improving briefing sessions. Finally, any particular design may need an *evaluation* to determine how team performance is affected. In total, the research framework represents an integral approach for investigating command center teams.

Maj. Worm *(Paper #9)* reports on work using the Action Control Theory (ACT) framework to examine the dynamics of human-machine systems in tactical mission settings and scenarios—in this case, time-critical air traffic control, process control, emergency response, and military operations. ACT is a composite framework encompassing: cognitive systems engineering; systems and control theory, and cybernetics; decision making in complex command and control; and psychophysiology. Worm integrated ACT with the Tactical Real-time Interaction in Distributed EnvironmeNTs (TRIDENT) method to assess workload and tactical performance in battalion-level battle command situations. He found significant relations between workload, time pressure, cognitive complexity, and physiological stress responses. Worm argues that the ACT/TRIDENT approach will facilitate: (1) identifying limiting factors of a specific individual, unity, system, procedure, or mission; (2) assessing the magnitude of influence of these factors on overall tactical performance; (3) proposing measures to support, control, and improve insufficient capabilities and contribute to successful accomplishment of future missions.

Maj. Craciun *(Paper #10)* focuses on information overload for land-based tactical electronic systems. Given improvements in electronics and computer technologies, electronic warfare systems have increasingly relied on computers to process information in a dense signal environment. Nevertheless, operators can never be completely eliminated from the system. Yet human capabilities have not kept pace with technological developments in the complex and diverse processing tasks and roles for EW systems. Craciun argues that computers and operators take different approaches to information flows for key tasks. Consider emitter identification and evaluation and reporting, tasks that cannot be performed fully automatically and need quick reaction times from the human operator(s). Computers draw very specific based on processing pulses and signals using fixed format commands. By contrast, human operators draw conclusions based on their perception of the whole electronic environment (derived from experience and indicators), even when there is not enough data. Visualization technology and techniques can reduce clutter and isolating critical signals, thereby helping the operator to focus only on the critical information needed for key decision points.

Dr. Dudfield, Mrs. Macklin, and Mr. Fearnley *(Paper #13)* describe research into the use of shared large screen displays (LSDs) for visualizing the battlespace. They propose that use of LSDs, by presenting more complete and accurate information, can enhance situational awareness and increase the probability of better command team decision-making. Understanding the command team's information requirements is crucial to gaining these advantages. Just as important, however, is understanding and measuring how the design of the LSD can impact on Human Computer Interaction to best obtain the potential performance benefits of team decision making with shared information space. Their research suggests that LSDs can be particularly useful in briefing and team situational awareness applications. To do so, LDS must be flexible and re-configurable, designed around how the user team works rather than dictating how the user team works. They must support intra-team communication, but also support individuals carrying out tasks independently. Ideally, LSDs should be provided in both fixed and deployable versions with similar functionality, and be simple and straightforward to operate.

Dr. Grau, Dr. Hourlier, and Prof. Amalberti *(Paper #22)* report on their "Electronic Copilot" project, a human-centered design effort based on the philosophy of cooperative assistance to provide to a pilot assistance like that provided by another crewmember. The key is understanding how humans approach the need for cognitive compromise—changing reliance on automated systems depending on the situation, both in the external environment and with the pilot directly, and the perceived level of overall risk. The benefits of the electronic copilot are difficult to measure. Beyond the technical issues and the challenge of integrating artificial intelligence technology into knowledge-based systems, their principles of cooperative assistance offer hope for keeping humans in the loop of complex system control.

Research into application: Dr. Post and Mr. Hamaker *(Paper #5)* propose a support concept for staff planning they call SmartStaff. SmartStaff consists of individual workplaces, generation and representation of ideas, and shared interactive large screen displays. They evaluated this SmartStaff concept during a simulated operation by the Royal Netherlands Navy's Task Group Staff. Based on participant questionnaires, they conclude that SmartStaff provides better general support for group decision making than the current work environment. While the quality of the final plan did not markedly improve, SmartStaff supported better presentation and conveyance of ideas, facilitated time management, and decreased the ambiguities of the plans presented. Further research will examine why content did not improve, whether other types of teams may profit, and how team planning is actually carried out (e.g., satisficing, or best solutions).

Mr. Alexander and Dr. Gärtner *(Paper #12)* examine the use of the Electronic Sandbox—a virtual environment (VE) tactical situation display (TSD)—to support the military commander to process the huge amounts of highly dynamic information provided by sensor, communication, and information systems. TSDs are used in command posts in the field and at operation centers. In theory, using VE as a TSD simplifies the interaction with data, increasing situational awareness and reducing operator workload. Alexander and Gärtner sought to build on the sandtable metaphor by enabling dynamic, real-time interaction and three-dimensional changes of point of view by multiple operators working in the virtual scene. While they found the approach promising, further research is needed to discern sensible uses in differing cooperation environments varying the numbers of operators, the time/space combinations, and cooperation concepts (e.g., conference versus workshop).

Collaboration is of little or no value itself if it does not improve mission effectiveness. Mr. Chapin and LCDR Dodd *(Paper #24)* report on the use of collaboration technology (text chat, voice audio, application sharing, whiteboards, and web-based technology) in Operation Allied Force to support deliberate and crisis planning and operations. Collaboration allowed United States European Command's geographically separated sites to work as a team and manage increased battle management complexity by mitigating the effects of information overload, improving team decision-making, and synchronizing situational awareness. Working with NATO allies in a collaborative environment will likely be an ever-increasing operational requirement. They report that performance, reliability, and simplicity were the primary factors that enabled collaboration to be accepted and used. Successful collaboration requires a process owner with existing or formally announced, delegated authority and recognized responsibility. It also requires a documented concept of operations. Collaboration does not replace the need for the right combination of well-trained, prepared personnel with access to current and accurate information. But the operational lessons learned demonstrate that judiciously applied to existing or modified mission processes, collaboration can benefit mission effectiveness.

CONCLUSIONS AND RECOMMENDATIONS

The following observations are based primarily (though not entirely) on participant comments made during the Capstone Panel and the open discussion.

Should HF research broaden its scope? Many of the presentations noted the promise of teams. But how do we measure the effectiveness of teams, and the impact of collaborative and visualization technology and tools on team effectiveness? More broadly, Dr. Dvorjak asks, how do measure the non-measurable, non-predictable part of technical systems, the influence of emotions, panic, etc.? Only by going beyond the measurable world. Dr. Gershon noted that evaluating the value of a phone conversation, leadership styles, or interpersonal relations is very difficult. He proposed that those in the HF field thrive to integrate measurable and non-measurable (e.g., intuitive) evaluations, and therefore must themselves team with others to evaluate team effectiveness, including (for example) designers or artists or behavioral scientists—people who understand how things work intuitively. Other participants countered that HF research is already multi-disciplinary, sometimes integrating people who understand cognition, physical limitations, and human intuition with designers to look at usability calculations. For example, examining the process of learning through storytelling is already a standard process used in design development. The HF field, as Dr. Essens put it, is a mixed bag, involving several different disciplines, some early on in the design phase of information management systems, and others at the end of the process (testing the system after completion). Most agreed that multi-disciplinary design teams (whether

HF-trained people are in the minority or the majority) offer the best approach.

Gén. Franquart argued that the problem of decision is very different according to the level of decision and the level of responsibility in the decision. Tactical decision, for example, are very different that strategic or political decisions. Staff-level decisions (often team-centered) are very different that command-level decisions (usually unitary actors). HF research can help analyze the problem from different levels of responsibility and action. Lt. Col. Pugh agrees, noting that in combat at the tactical level, operators are concerned primarily with what is happening immediately around them. In such environments, information is almost peripheral, interfering with thought processes.

Dr. Léger suggests that HF research has relied too much on the ability of decision-makers to make good decisions. We have to prepare for unpredictability. Dr. Boff agrees, noting that the operator is ***not*** a perfect receiver of information. We should expect that decision-makers are not going to perceive information in the way that we designers might expect. In the end, battlefield information systems must match the logic of the operator. Hence, we must design in adaptive interfaces to allow the operator to use his or her own strategies.

To simulate or not to simulate? Prof. Værnes (Keynote IV) argues that the science of information processing has become too segmented along the line of specific experimental tasks. Because little information is exchanged among research groups, the science has produced a lot of information but contributed little to our understanding of how humans function in real-world settings. Human information processing is a complex system that will never be understood as a sum of its component parts. Human factor specialists must widen their perspective beyond the simple tasks that dominate current research. To analyze the decision support considerations of the usability of information in battle management operations, we must both conduct laboratory simulation experiments and collect valid information from the "real" battlefield environment.

While some participants agreed that research should look at real combat environments, others cautioned that the value of simulations should not be overlooked. Lt. Col. Pugh emphasized that we have to have simulation to be able to predict in advance what works, to provide enough foundation and theoretical support to mold new technology to meet operational needs, and get it right the first time. A spiral research agenda may be best, alternating simulation and combat experiments using observation, simulation, and combat experimentation where appropriate, cost-effective, and applicable.

Part of the debate stems from the financial pressures to create "demonstrators"—that is, prototypes of limited capabilities designed to convey principles and applications Dr. Essens referred to this as the effort to make artifacts work to get money (research artifacts) rather than focusing on real issues. But, as many noted, the fact of life is that the needs of customers, including their learning needs (e.g., disbelieving pen and paper studies or proposals they cannot touch and feel), will continue to drive research.

On visualization: Dr. Eggleston believes that based on the research presented, some progress has been made on visualization from a HF perspective. Yet we still have no consensus in the HF discipline on how to design, build, and evaluate visualization. Dr. Essens suggests central to the development of visualization from a HF perspective is understanding the task and the task environment. A lot of the HF visualization research relates to individual interfaces, not to developing a common operational picture. Dr. Boff suggests that this lack of attention was a significant hole in the symposium.

On collaboration: Figure 2 presents the collaboration space, showing different combinations of time and space; from synchronous (same time) and persistent (same place) in the upper left, through asynchronous and non-persistent unpredictable collaboration in the bottom right. Illustrative collaborative tools and techniques are provided for each space/time combination (in Italics).

Figure 2: The collaboration space

		Time		
		Same (synchronous)	**Different but predictable**	**Different and unpredictable**
Place	**Same (persistent)**	*Meeting facilitation* Papers 3, 4, 5, 10, 12, 13, 14, 16, 17, 22, 23	*Work shifts*	*Shared, virtual space*
	Different but predictable	*Tele/video/desktop conferencing*	*Electronic mail* Papers 2,8	*Collaborative writing*
	Different but unpredictable	*Interactive multicast seminars*	*Computer bulletin boards*	*Workflow*

All: Keynote I, II, III, IV; Papers 11, 19, 25
Unspeficifed: Papers 1, 6, 9, 15, 20, 21

As indicated, we have suggested in which combinations the twenty-six symposium contributions operate. All the keynote addresses and three of the papers operate throughout the collaboration space, and two papers concentrate on asynchronous, non-persistent combinations. The largest number of contributions fit into the same time/place combination. Yet in the real battlefield environment, collaboration (between human and machine, individuals, and teams) takes place in forms that span geographic, temporal, and organizational boundaries. And in conditions of stress, persistence of information may be required to effect information transmission. This suggests that HF research should expand its coverage throughout the collaboration space, to include cross-cultural collaboration (a topic absent from this symposium).

The challenge of institutionalization: The nature of collaboration systems as a "disruptive technology" (requiring changed operational procedures and practices) means that broad high-level management support is a necessary condition for success. Further, collaboration systems have to be "institutionalized"—that is, they must become part of legitimate and ongoing practice, affect structures and patterns throughout the organization, and be supported by other aspects of the system within the organization's domain. Because efforts approved at the top can be frustrated by peripheral and lower-level participants within an organization, the system of rewards also has to change to encourage the building of coalitions and teams to support and implement the new tasks. The supporting network communications architecture also must be well prepared for deployment of a collaboration application.

The most difficult challenge is that of creating a culture of collaboration—creating an organizational culture and organizational readiness to change to support collaborative operations culture of collaboration. Working smarter means working together, not harder, and breaking down stovepipe processes in favor of more non-linear and agile decision-making models. The impact can be dramatic, as exemplified during the Kosovo operation when the Collaborative Contingency Targeting system enabled the Cruise Missile Support Activity and theater commanders to reduce the timelines for distributed targeting for Tomahawk Land Attack Missiles from days to hours. While costly, Mr. Chapin and LCDR Dodd suggest, a distributed information architecture may help ensure a timely, appropriate, and effective response. HF must work on measuring the value of such architectures to aid in system design.

Finally and most importantly, collaborative and visualization systems must be used if they are to reap benefits. This means that intuitive interfaces are needed (to the extent possible), and adequate (and repeated) training programs must be implemented throughout the organization. People revert to that with which they are familiar when they are not comfortable with the new. This is especially true under conditions of stress.

Keith B. Alexander
Brigadier General, United States Army
Director of Intelligence
United States Central Command
7115 South Boundary Boulevard
MacDill AFB, FL 33621-5101
USA

SUMMARY

Commanders have always faced significant challenges in visualizing the battlespace; how well they have succeeded has determined their ability to shape the battle to their advantage. As our weapons technology advances and shortens decision times, it is imperative that our warfighters be able to visualize the operational situation and to share this picture up and down echelons and among coalition partners. We can take several steps to improve our ability to pass a common relevant operational picture of the threat among our various components, coalition partners and national leaders that is vital to synchronize combat operations.

THE PROBLEM

The inability to clearly visualize the friendly and enemy battlefield situations is a major problem facing Warfighters and their staffs. There are four major reasons we have not solved this problem. First, we have a limited ability to rapidly process, exploit, analyze, and fuse the large amounts of information available from the many sources providing input. Second, we lack the tools needed to help us comprehend that information. Third, there is a shortage in numbers and types of sensors and systems needed to display accurately and automatically red-force and blue-force information. Fourth, limited tactical communications hinder our ability to rapidly share information across the battlefield in a synchronized manner among all our command and control elements. This last issue recognizes the many difficulties involved in passing information among the various echelons, from national through tactical levels, among various functional disciplines, and perhaps the biggest problem, and one of particular interest to this group, passing information among coalition members.

These problems exist for a number of reasons. It is difficult to synchronize the various acquisition efforts to best leverage advances in computer technology. Each of our Services approach information processing and battlespace awareness differently. Visualization requirements vary from nation to nation within our ever-changing Coalition. While a number of tools are available to help us understand this information, they are not always compatible with the many types of software and hardware obtained through various acquisition programs. As a consequence, we often purchase Service-specific, but non-interoperable, software and hardware. While this helps us within our Services and within each of our nations, it greatly complicates our ability to operate cohesively within a multi-national, joint alliance.

Budget limitations constrain the number of sensors we procure, often resulting in an incomplete, and inaccurate picture of the battlefield. Communication among mobile units is difficult and usually constrained by bandwidth. Since many of our tactical operations command posts adapt their information displays and management to meet specific requirements, we often have a problem formatting information to meet the specific needs of subordinate elements and functional areas.

An associated problem within communications is multi-level security. This problem has plagued all of us. Each different security classification (Top Secret, Secret one nation only, Secret releasable to our allies, or in this case, NATO) requires different handling instructions. These multiple security requirements and the manual tasks required processing them cause additional delays in passing information among organizations and echelons.

Paper presented at the RTO HFM Symposium on "Usability of Information in Battle Management Operations", held in Oslo, Norway, 10-13 April 2000, and published in RTO MP-57.

THE RESULT

The problems outlined above produce several significant consequences. The most obvious is information often arrives late and is outdated when it is received. However, since it is usually the best information available, it is normally integrated into the current intelligence picture. Since this may occur at various times at the various echelons and functional areas, it results in an unsynchronized, inaccurate common operational picture across the battlefield. This creates problems synchronizing information as each command post may have a slightly different view. Because we lack the ability to pass a common relevant operational picture of the threat among our various components (Air Force, Navy, Army, and Marine Corps) and to the joint and national levels, our ability to synchronize combat operations is less than efficient.

REAL WORLD EXAMPLE

At Headquarters, United States Central Command, we have a number of automated capabilities, but we do not have the ability to share a real time intelligence picture with our national agencies, Joint Staff, subordinate commands, and allies. We maintain our common picture on a map board, and then transfer this onto Power Point presentation slides that are emailed to all concerned. The most significant problem with this is the timeliness of the information being passed. It takes time to create and mail the presentation, ensuring much of the data is outdated immediately. At the same time, those to whom we are mailing our slides are probably getting updated textual information before they get our slides. The differences between the real-time reporting and the dated presentation slides cause confusion. Video teleconferences help synchronize our efforts during crisis, but these conferences consume time and are not efficient.

IMPACT

There is another much more serious, but less visible, consequence of the problem. Our lack of an accurate and timely common operational picture negatively impacts every step of the intelligence cycle. The intelligence cycle should not be viewed as a sequential system, but rather as a series of steps, all inter-related, and all happening simultaneously. It goes on at every echelon; each echelon depends on input from higher, lower and adjacent elements. Finally, and perhaps most importantly, this cycle must be linked to operations. Operational decisions not closely linked to the intelligence situation are doomed to failure. First, I will briefly discuss some of the steps of the intelligence cycles and present some thoughts on what we can do to fix this problem. Then I will discuss battlespace visualization requirements and some of our thoughts on solutions.

PLANNING

In order to plan among our echelons, components, and allies, we must have a common picture of the battlespace and a real-time collaborative ability to link our planning elements together to develop and synchronize a plan. We must have the ability to understand and comprehend the information displayed to us. Based on that comprehension, we must also have the ability to develop future courses of action, branches, sequels and other possibilities upon which we can base our plans.

COLLECTION MANAGEMENT

One of the biggest challenges we face is managing our national, theater and tactical collection assets, because we lack the dynamic collaborative ability to display what assets at each level are doing or are going to do. This process is even more complicated when we attempt to synchronize collection assets with our allies. The results are obvious; we waste a lot of effort duplicating collection missions, exploiting and reporting similar activities on the battlefield, while simultaneously missing opportunities to collect on events that may have had equal or greater importance. We need to show what will be collected from various assets so we can trade-off between platforms for the most efficient collection deck. We also need the ability to predict what we can collect.

EXPLOITATION

Many of the exploitation problems stem from the collection management problem I just described. But even if we fixed the collection management problem, we still do not have the ability today to consistently focus our exploitation capabilities on the most pressing problems first. Nor do we have the ability to easily collaborate among exploitation centers to optimize our efforts. Finally, the outputs from our exploitation centers are often reports that are very difficult to automatically integrate into the common relevant operational picture. Collaboration among collection managers, analysts and all exploiters would significantly improve our exploitation shortfalls.

ANALYSIS

Perhaps the group most impacted by these problems is our analysts. Because they cannot see the plan or the collection management picture; because they rarely have the insight of the exploitation center; and because they often receive the information after a time delay, their already incredibly complex mission to integrate information into a common picture is made almost unattainable. These analysts need the ability to collaborate and view all the steps of the intelligence cycle as it progresses. They must be able to automatically sort, parse and display information in various text and graphic ways, including electronic two-dimensional and three-dimensional displays. Finally, because their output must support a host of consumers, these analysts must be fully synchronized with operations.

DISSEMINATION

Finally, we must be able to disseminate this information amongst all consumers in a timely manner. We must be able to quickly pass it to multiple echelons and among our allies, often with differing security requirements, in to support decision-making for all. This would be further enhanced through web-based technologies and other available collaborative tools.

TO FIX THE PROBLEM

Now, some thoughts on how we fix this problem that hopefully will be useful in stimulating further dialogue. First we have to develop and evolve a common, relevant operational picture for operations and intelligence that can be used by all operators, collection managers, exploiters and analysts. Not everyone needs to look at the same picture at the same time; however, everyone must have the same information, which can be tailored and displayed to best support their requirements to accomplish their job or function. To develop this picture, we have to make our data feeds and systems interoperable on a wide area network all can use. This network must have different security layers to protect information, similar to the ways the commercial market is securing the Internet for business today. We also need different types of displays at various echelons to meet user needs. Some will need large-screen displays for staff planning, execution and operations. Others will need individual displays to conduct their business. All need access to timely and accurate information. Finally, all must have access to tools that help them manage and display the information in ways that they can understand, so that they may efficiently react to dynamic environments.

VISUALIZATION REQUIREMENTS

One of the big challenges we all face is articulating our visualization requirements in a manner that leads to the best solution. We need the ability to bring in all types of data and to actively query databases for additional information when needed. This must include all available forms of information. We need different types of displays and different types of backgrounds to facilitate comprehension and decision-making. Ideally, these displays and the information provided would also be common among our various coalition partners. We also must ensure that data is provided the appropriate levels of security, while still ensuring everyone is efficiently connected.

SOME THOUGHTS

Modern technology is only half the answer. To make all that I have discussed a reality, we also have to have a common set of tactics, techniques and procedures for manipulating and using this information, and we must train together. Once we develop these procedures and train our people, we must then exercise together, and evolve the way we think.

CONCLUSION

Visualizing the battlespace is indeed a very difficult problem. Commanders who have had the best understanding have always done the best in conflict. It behooves us to provide our warfighters with the best possible visualization capabilities.

Winning in Time: Enabling Naturalistic Decision Making in Command and Control

Colonel William C. "Hook" Louisell, USAF
56th Operations Group Commander
14185 West Falcon Street
Luke AFB, AZ USA 85309-1629
Tel 623 856-5950 Fax 623 856-6382
e-mail hook.louisell@luke.af.mil

Network-Centric Warfare

Key US proponents of the Revolution in Military Affairs described future war as a system of systems in which dominant battlespace knowledge would enable a system of sensors and shooters to be connected for the purpose of engagement through an advanced, information technology-based command and control function (Fig 1). Through dominant battlespace knowledge, the command and control function would achieve efficiency levels which would greatly alter the nature of conflict – current time constants in the decision, action, feedback loop would be drastically shortened. The nature of weapons and platforms would change and the organization and training of forces would change.

Stuart Johnson and Martin Libicki, in their National Defense University publication Dominant Battlespace Knowledge, offer an analytical tool to understand the value of dominant battlespace knowledge in a network-centric force application concept (Fig 2).

Perfect command and control (C2) is achievable only with perfect information – dominant battlespace knowledge. Dominant battlespace knowledge essentially represents the command and control function's understanding of the situation as near-perfect. Although this level of understanding may be achievable in certain environments, its potential is challenged by the emerging nature of conflict – one described by Samuel Huntington as the Clash of Civilizations. Huntington sees future conflict as humanistic, driven by fault lines between cultures and economies. Conflict of this nature challenges the ability to achieve dominant battlespace knowledge. Furthermore, the centers of gravity in such a conflict are much more broadly distributed across a nation's economy, infrastructure, international relationships, internal divisions and armed forces.

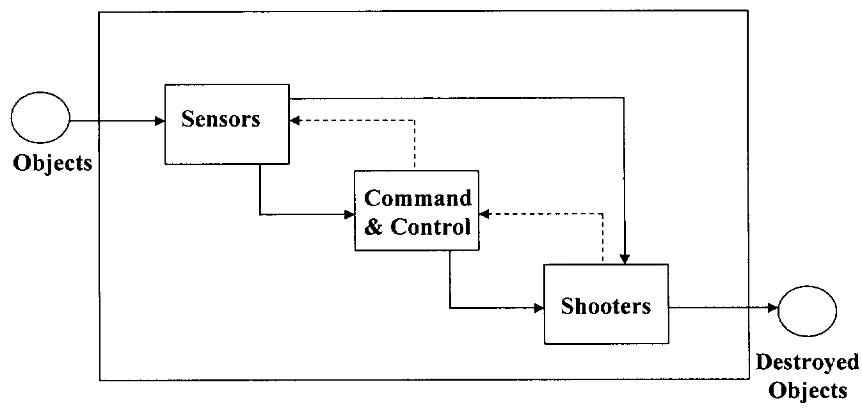


Figure 1: System of Systems Approach

Paper presented at the RTO HFM Symposium on "Usability of Information in Battle Management Operations", held in Oslo, Norway, 10-13 April 2000, and published in RTO MP-57.

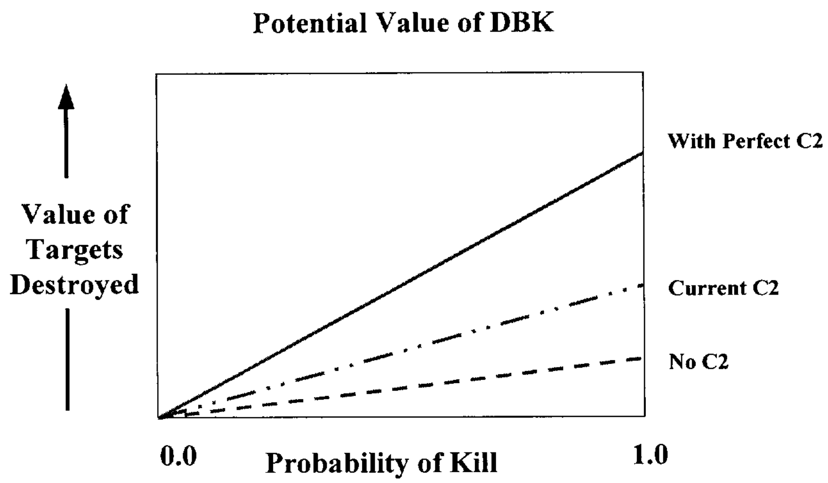


Figure 2: Dominant Battlespace Knowledge (DBK) in Command and Control (C2)

Changing Face of National Power

At the same time the nature of conflict is changing, the nature of national and Alliance power is changing. The information age creates the potential for a seamless system of power resources which spans a spectrum from the strategic use of information and information operations to the application of information-based strategic and tactical weapons systems. In the future, a multi-dimensional approach will emerge in which all elements of national power including economic instruments, political instruments, information instruments, and military missions are applied synergistically across an info-kinetic power spectrum (Fig 3).

This will have a significant impact on military actions at the operational level. No longer will the task force commander be purely concerned with the impact of his actions on the enemy's forces. Nor will the destruction of forces and the seizure of strategic resources be the singular determinant in changing enemy behavior. The task force commander will, to a larger degree than ever before, have to integrate actions and the actions of others into a continuous, coherent, multi-dimensional plan.

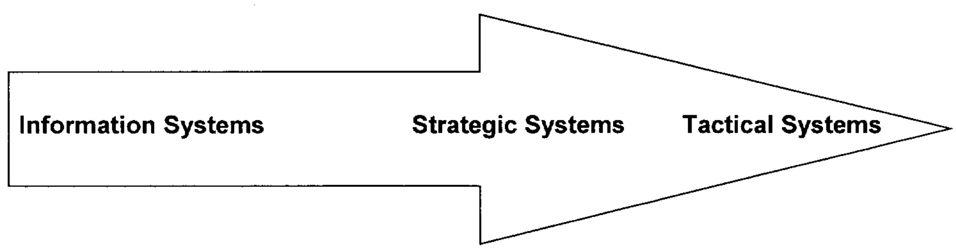


Figure 3: Info-Kinetic Power Spectrum

Complexity at the Operational Level

The operational decision environment will become non-linear with non-linearity defined as a condition in which a system disobeys principles of proportionality and additivity. Non-linear systems provide erratic or "chaotic" responses to inputs – cause and effect are difficult to track through a series of nodes in which forces interact. Achieving a sufficient level of understanding in these non-linear enviroments will require special tools and familiarity with complex decision techniques.

Decisions in Environments of Complexity

Study of decisions in complex scenarios reveals two fundamental styles -- an Analytic Style and a Naturalistic or Recognitive Style. The analytic style is characterized by a systematic data collection effort and a formal analysis and evaluation of various options. The naturalistic or recognitive style is characterized by an intuitive use of patterns leading to decision based on experience in like or similar situations (Van Riper and Hoffman, 1997). Experts in dynamic decision environments -- the master chess player, the NBA basketball player, the great general -- make decisions intuitively based on the comparison of current situation understanding to past situations and outcomes. These experts take advantage of the speed of the naturalistic or recognitive approach to act quickly – to outmaneuver their opponents by reducing the time to determine the action required. (Trotter, 1986)

System Evaluation

Understanding the complex causal chains in a non-linear system requires the use of one of a limited number of powerful system evaluation techniques. One such technique is Systems Dynamics (Inset 1). It was developed by an MIT professor, Jay Forrester. Forrester modeled webs of activity that

Systems Dynamics – A Snapshot

Prior to modeling a System of Alliance power, it is necessary to establish a fundamental understanding of the Systems Dynamics method. As inferred in the previous section, the Systems Dynamics approach to system evaluation is based on the principle of causal chains made up of paired variables that are related through physical or information flows. In the relationship, an independent variable acts upon the other variable, the dependent variable. Variables are paired in graphic form to show the direction of the influence and the polarity of the relationship. The key variables of interest in a Systems Dynamics model are called level variables. Levels are deteriorated or increased by rate variables. The relationship between level and rate variables is depicted by a solid line with an arrow head indicating the direction of influence and a plus or minus sign to indicate the polarity of the relationship. In a positive relationship, both variables move in the same direction. In a negative relationship the dependent variable moves opposite the direction of the independent variable.

Inherent in the evaluation of a Systems Dynamics model is the identification of feedback loops in which causal streams and the information relationship within those streams cause the system to exhibit characteristic behaviors. First and Second order positive feedback loops grow or decay exponentially once moved from an equilibrium state. First order negative feedback loops correct from a deviation to an equilibrium state. Second order negative feedback loops oscillate around an equilibrium value. Identifying feedback structures within a system or sector and understanding the behavior associated with structures present, will allow prediction of behaviors and the evaluation decisions which policy makers make in an effort to try to influence a system's behavior.(Drew, 1998). This description is not an all inclusive primer on Systems Dynamics. It is designed only to allow the reader to evaluate and appreciate the model of Alliance power which will be developed and explored in subsequent sections.

nset 1: Systems Dynamics Methodology for Depicting Causal Streams

were interrelated through shared information, shared physical resources, and interactive feedback loops. He demonstrated system characteristics between related variables and was able to develop causal chains that could be evaluated numerically or graphically to provide insight to complex and counterintuitive behavior. He did this for a world model, for commercial industries, and for government evaluation of policies. Forrester identified that systems are made up of basic feedback structures which have known behavioral characteristics. He demonstrated how the elements of system structure and behavior could be used to understand the behavior of large, multi-discipline, complex systems of interaction which he terms as metaproblems (Martin, 1996) (Drew, 1998).

System of Alliance Power

In order for military commanders to develop a systems view of national and Alliance power, we need a model that links together the various sectors of influence of the elements of power – economic policy, political policy, information policy, and deployment and application of military force.

Economic Sector

The economic sector, contained in the total power model, is represented by the relationship between Capital Investment, Capital, Industry Output, and Gross National Product (Fig 4). Note the positive feedback loop which is formed by this causal stream. This positive feedback loop, along with others identified in the successive sectors, are points of leverage for policy application.

Military Attrition Sector

A military attrition model is included in the integrated national security model. It represents a classic force-on-force battle in which force attrition is the determinant of victory. The attrition model is a second order positive feedback loop -- once influenced in the proper direction through an overwhelming initial attack, it can be pushed, especially if time is compressed, reducing the potential for restocking through domestic or foreign production. This positive feedback loop is central to evaluating force application policies.

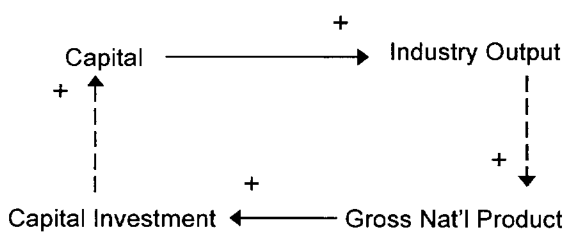


Figure 4: Positive Feedback Loop in the Economic Sector

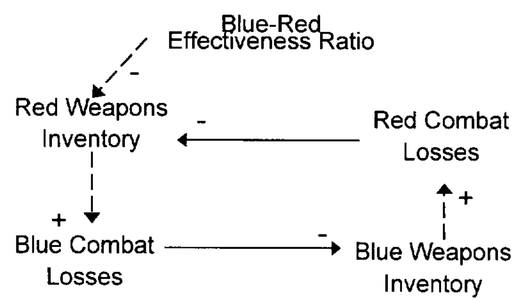


Figure 5: Positive Feedback Loop in the Military Attrition Sector

Political Power Attrition Sector

The political power attrition sector establishes the linkage between the power of the political leadership, the will of the people, and the perception of the international community (Fig 6). This sector model is in draft form and, is subject to refinement. In its current form, it is a conceptual tool to understand the causal relationships between the factors that work to provide a political power base.

This sector is central to understanding the effect of actions on the key measure of effectiveness – the willingness of the enemy to continue the conflict. Targeting the enemy's will is not new, it was part of the total strategy employed by the ancient Chinese warrior, Sun Tzu. What is new is that information combined with rapidly applied, precise force introduces an ability to shock the enemy and cause an early question in the minds of the people (Ullman and Wade, 1996). The keys in this sector are the linkages between the International Perception, Political Power of the Leadership, and the Will of the People.

Major influencing factors from the other two sectors are triggers to set in motion the two second order positive feedback loops contained in the Political Power Attrition Sector.

Information Multipliers

Imbedded in the model are Information Multipliers that are displayed as auxiliary variables at points of influence. These represent places where information operations can be used to magnify the effect of conventional actions. Learning to capitalize on these points of leverage will propel the system approach of power into the future giving the Alliance a whole new dimension from which to approach security issues.

Model of Alliance Power

A model of the system of national power is shown on the following page (Fig 7). It is displayed in a visual format – a causal diagram which allows the decision maker to see the interactions between and within the various components of an adversary's power base. Key points of leverage have been identified as positive feedback loops. These are not all inclusive, but they are the pressure points that can be used to resolve crisis at any point from identification up through force application.

A Model as a Tool for Leadership

The system level model illustrates the linking mechanisms between the previously described sectors. Understanding the system aspect requires visualization of the interactions between the various sectors of the model. Although a crude representation of the whole system, the model has immense value in demonstrating the system aspects of national and Alliance power. It serves as a tool to build a broad set of reference patterns that future leaders may use in complex decision arenas – visualization and patterns enable recognitive or naturalistic decision processes (Czerwinski, 1998).

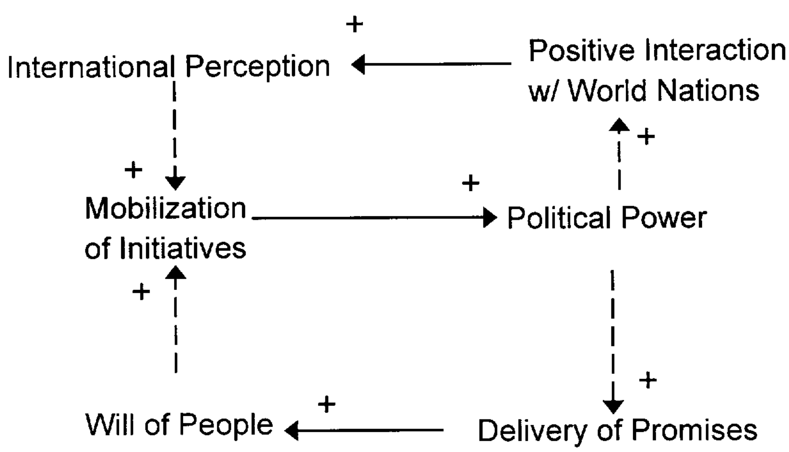


Figure 6: Positive Feedback Loops in the Political Power Sector

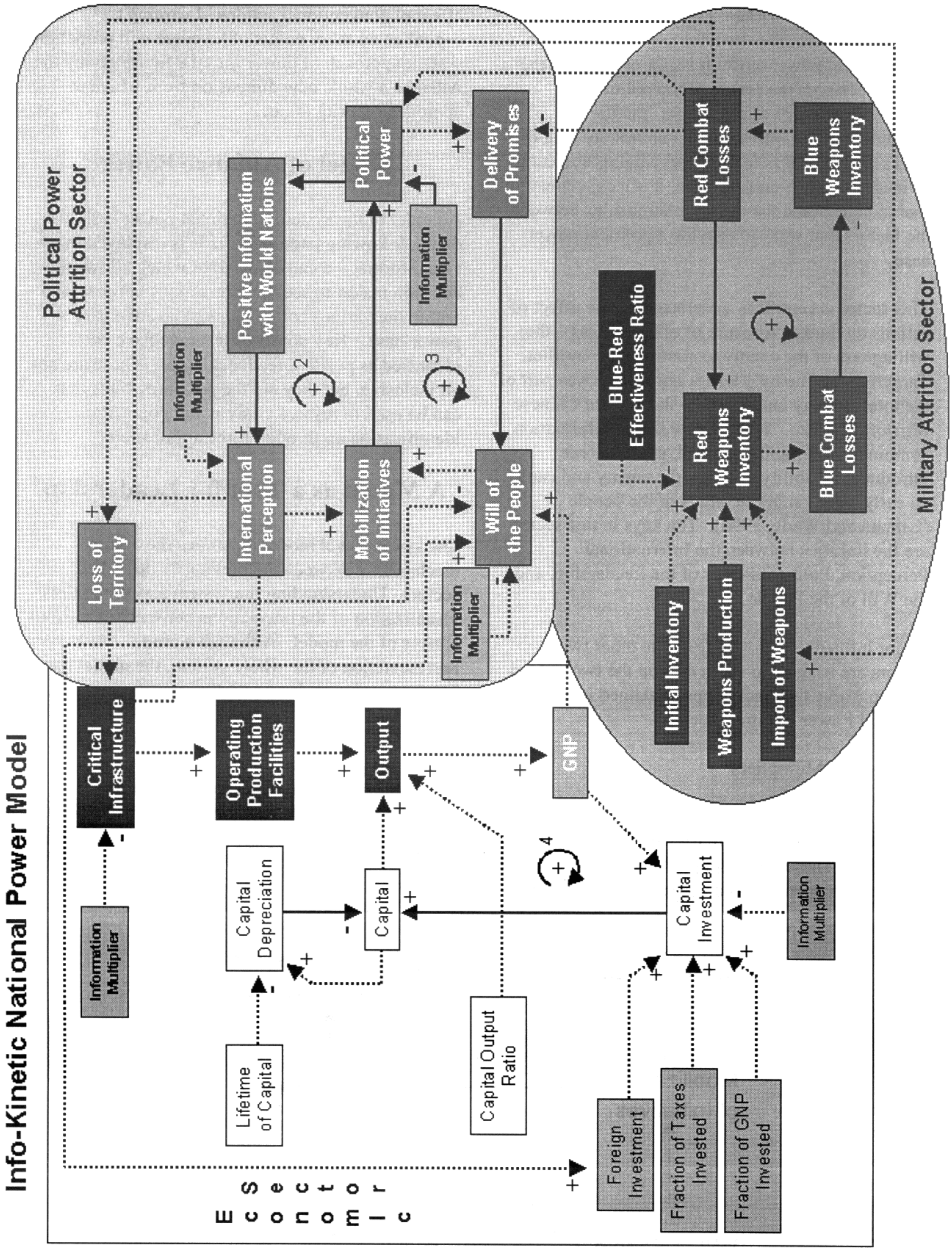


Figure 7: Causal Diagram of a System of National Power

At this point, we can update the chart proposed by Johnson and Libicki, revealing that we may be able to use visualization models as aids to learning -- enabling excursions into efficiency levels previously possible only through dominant battlespace knowledge (Fig 8) (Czerwinski, 1998).

Developing the Model

The first step in preparing the model is to employ a panel of experts from across the participating departments and agencies to more fully develop the definition of the model's variables and to validate the paired relationships between them. Once this step is complete, the model can become useful in the qualitative analysis of policy and strategy options.

The second step is to develop the mathematical relationships between the variables and to use the model to examine historical situations to calibrate the model for specific potential adversaries. This will make the model useful in quantitative terms. Once this step is complete, the model can be further incorporated into strategy experiments and gaming.

The third step is to use it as an evaluation tool in programming functions to test alternative procurement and application strategies. The results of various trials could be used to "what if" scenarios in order to provide leaders with an envisioned pathway towards a desired state.

Conclusion

The emerging complexity of the international security environment requires a broader, more integrated approach than was required in the Cold War era. This challenge can be met by an integrated application of the elements of national and Alliance power enhanced by an information technology network that enables collaborative formulation and execution of policies. This networked approach will create a more complex environment for leaders in each of the engagement elements. Decisions made in one arena will have direct intuitive and counterintuitive downstream effects that must be understood. Systems Dynamics offers a simple technique that can be used to map the system of national security measures enabling an understanding of the leveraging effects of networked, information based warfare. In the future, information will be as essential to warfare as any physical weapon system technology. With a valid model to serve as the propelling center of thought, information-based warfare will develop at rates that will provide a renewable competitive edge for the Alliance.

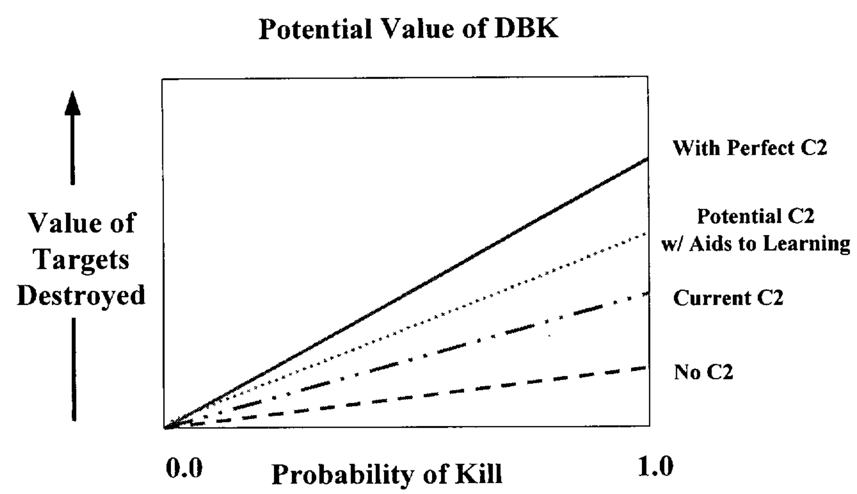


Figure 8: Leveraging Command and Control Through Aids to Learning

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Battlefield Information Systems in Air Warfare

Wing Cmdr G. Stapleton
Deputy Station Commander
RAF Lossiemouth
Lossiemouth
Nr Elgin
Scotland
IV31 6SD

Malcolm James Cook[1],
University of Abertay Dundee
Centre for Usability Test and Evaluation
Division of Psychology
158 Marketgait
DUNDEE
DD1 INJ
Scotland
U.K.

Henrik Artman
National Defence College
P.O. Box 27805
SE-115 93 Stockholm
Sweden

Tel. + (44) 1382 308178
Ans + (44) 1382 308184
Fx + (44) 1382 223121
e-mail m.cook@abertay.ac.uk

"Les choses simples sont difficiles à expliquer" Henri Matisse.

"If you know the enemy and know yourself, you need not fear a thousand battles. If you know yourself and not the enemy, for every victory you will suffer a defeat. But if you know neither yourself nor the enemy, then you are a fool and will meet defeat in every battle." Sun Tzu Circa 510 B.C.

Abstract

Intelligence systems are designed to enable self-knowledge and knowledge of the opposition to achieve knowledge superiority. The basis for knowledge is the collection, collation, interpretation and dissemination of information. Superior performance in the marshalling of information sources, the creation of shared knowledge and the projection of information in future plans represents what has been called information superiority (Endlsey and Jones, 1997).

Almost all stages of knowledge development involve interpretation and the introduction of selective filtering or emphasis. The integration of computers and communication systems afford the capability to share large volumes of highly processed information. There is a significant difference between information and knowledge in that the creation of knowledge involves the imposition of this interpretive framework to organize and group information in meaningful ways. Often information must be filtered to remove noise and to exaggerate the salient points. In addition, assumptions concerning the validity of the information sources must be exercised to ensure that deception and sensor capabilities are taken into account.

The construction of this shared reality amongst the users of the system depends on social, cognitive and experiential processes guiding the flow and management of information. The situational awareness of the team operating the information systems is a vital part of the effective operation of the system because it helps to direct cognitive resources and support filtering of task-and context-irrelevant information. It is possible that "the knowledge of results when attention is allocated to a zone of interest" (Fracker, 1988) are poorly articulated across the team and this results in obfuscation of the prioritized goals or the context. This is important because of the likely relationship between situational awareness and the quality of the decision making process (Endsley and Jones,

[1] This report has been written wholly by the first author and he accepts full responsibility for the contents of the document. However, significant elements of the reports were influenced by numerous discussions with the other contributors and by papers submitted by co-authors elsewhere.

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1997). Team situation awareness is more complex than additive models of individual situational awareness as some have suggested (Klein, 1993) and simply aggregation of collective inputs may not adequately predict performance outcomes (Salas, Prince, Baker, Shrestha, 1995).

The design of any large-scale socio-technical system for sharing, processing and managing information resources requires careful analysis in the development, implementation and operation to ensure that the system contributes effectively to the performance it is intended to support. Many analyses of such systems focus on process variables without establishing their relationship to outcomes. For example, it has been found that communication measures may actually fail to predict performance outcomes because they do not address the mediating process of knowledge realization across the team (Cook, Angus, Brearley and Stewart, 1998). This finding has been recently supported by work demonstrating that communication may not change significantly even though the cognitive capacity to use the information exchanged does across the day (Reid, 2000). In addition, it has been shown that more commanders may actually send fewer messages to their teams but spend more time planning (Artman, in press).

What seems to be critical is the capacity to process information further to create the comprehension stressed by Endsley (1995, 1996) as a form of second level situation awareness. This is in accord with the view that the process of making or creating knowledge for decision making is more instrumental in preventing faulty decision making than processes of review given the time constraints of many military tasks (Cook, Angus, Brearley and Drummond, 1998). There are many examples in the literature where the processes of intelligence development, or operation, or both have been poorly managed with catastrophic consequences.

It can be argued that the reasons for such system level failures in socio-technical information systems can be traced to three perspectives that are inappropriately expressed in the design and operation (see Flowers, 1996; also Luff, Heath and Greatbach, 1994). The first perspective concerns the user(s). As Artman (1999a) has expressed very cogently the user is often denigrated in the development process as the root of many problems and the newly developed system(s) are intended to manage the user's behaviour to achieve greater levels of performance. Thus, so-called user-oriented design is only a rhetorical statement concerning the existence of contact with the user-population and not a guarantee of the effective elicitation of user requirements nor is it a tacit acknowledgement of the central role of users in decision-making processes.

The second perspective concerns the potential different user groups, or system clients, and the way that information sharing is prioritized among the different groups in relation to their air warfare roles. Air warfare in the form of composite air operations is a complex process of integrating diverse assets effectively and one of the factors that may determine the success of this annealing of assets across and within packages is the use of information systems (Directorate of Air Staff, 1999).

The third perspective concerns the effective operation of the battlefield information systems in a diverse range of contexts both in space-time and in composition. Failure to acknowledge the large array of factors that shape performance in the use of information systems can undermine the operation effectiveness of deployed systems. Indeed, it can be argued that operational issues and limited foresight in design can be good examples of the latent pathogens that may generate total system failure in the complex systems (Reason, 1990, 1997).

Cunning Cavemen and Dumb Machines

One of the concerns of Artman (1999a) was to draw attention to the assumptions underpinning many system developers views in relation to the user population their systems were designed to support. Artman felt that on the one hand there was a tendency to focus on the negative attributes of the human and on the other, to dwell upon the strengths of machine intelligence. This bias in the reporting of capability was clearly problematic for a number of reasons. First, the human being was the final line of control and it was the human being that would take the crucial decisions. Thus, it was important to address the user's needs in more than just the palliative sense, which many information technology projects do at present. Second, the capability that machines have is more focussed on basic information processing and any notions of so-called intelligent or adaptive function are both rudimentary and costly to validate at present. Thus, the thinking and deciding is left to the human operators and managers.

In relation to total system function there is no doubt that the raw and unflagging power of computers in processing information is valuable. The new links between computers, that enable high-speed digital exchange of information via secure networks, are both attractive and valuable in maximizing the cognitive resource utilization of all participants. It is clear that "Operation Allied Force highlighted the blending of tactical implications with strategic issues – the blend being in the cockpit, where the pilot is the final part of the decision loop." (Penney, 1999, p.32). This integration of the front-line crews in the decision making process should be made with care to ensure that the limited cognitive capacity of the busy pilot is not overloaded and part of that process must include a credible sharing of information.

Pilots also need to develop confidence in their decision making because they need to feel able to take decisions without balancing constraints. Thus, one would imagine benefits of effective and knowledgeable support from fighter controllers with the role-specific knowledge, directing the information flow and negotiating appropriate actions with front-line crews. The concern with the quality of the fighter controllers is something which has been raised before (McManners, 1996) and it shows the way in which the cognitive and social skills of the individuals in any system shape the performance outcomes. It is clear that the human element is important because of the way that human operators are often called to account for failure. However, human and system operations are intertwined and ineffective design can generate inappropriate performance.

The information must be presented to human operators in a form and at a time in which it is possible and feasible to influence the on-going course of events. Human operators need to keep ahead of the curve and when they fall in line with it or behind it the potential for erroneous decision making is great. At present the use of technology fails to maintain an intelligently managed dialogue between the human and machine intelligence, with much of the workload associated with dialogue management reliant on the somewhat limited capacity memory of the human operator. This is even true in second order ways because operators are rarely able to interrogate systems for histories or to set timers to help them schedule activities at some future point in time. The passivity of the machine is deceptive in that for many activities the pace and temporal aspects are human driven. It is possible that the lack of context sensitivity on the part of machine intelligence is a major element of the dialogue between human and machine. Humans frequently despair of the inappropriateness of machine interruptions and the banality of the requests made.

The difficulty in designing for multiple users with differing requirements and the costs associated with disseminating information is in provision of equipment, equipment support and training. This operational complexity means that there is a tendency to centralize information system development, focussing on the needs of the key decision-maker or leader (Artman, 1999). This process of centralization may lie at the heart of the process of ineffective decision making in fostering the conditions for high workload and lowered situational awareness. In addition, this may increase the risk of Groupthink because it may tend to stifle participation in negotiated decision making. Even in military systems the social and contextual world is a constructed experience which is negotiated:-

> " A team of agents have a joint persistent goal relative to q to achieve (a belief from which, intuitively, the goal originates).. .In short, the notion of togetherness, of group and teamwork is based upon the notion of joint persistent goals, which are but individual goals associated with social, namely mutual, beliefs." Conte and Castelfranchi (1995, p. 153).

This general approach to command and control has been supported by a recent paper from Artman (2000) in which negotiation is one of the mechanisms used to share information. The two other mechanisms being attentive monitoring and the use of artefacts. Those operators at the lower levels of command, without direct access to information may feel dis-empowered and unable to contribute to the discussion without access to the relevant information.

The dialogue between humans and humans, and humans and machine intelligence or agents is a clearly a crucial part of the operational effectiveness in that human cognition is situated in an operational environment or domain which stimulates mental activity. The more passive the user becomes the less effective they may become in relation the decision making in the assigned task as their awareness of relevant information collapses. In many respects this acknowledges the general observations made concerning the processes involved in building situational awareness (Endsley, 1988) and the importance of active information capture.

It is possible that inexpertly designed information systems may at one and the same time encourage decreasing numbers of exchanges between crews and afford limited access to the information required for building knowledge. Or, the number and type of exchanges may vary little from that deployed in previous systems but the ability to use and comprehend information is significantly impaired. For example, the workload of managing the dialogue may increase and reduce the amount of resource available for further processing. Or, the detailed information in the exchanges may not activate the appropriate elements of the participants' mental models and create comprehension.

Situational Awareness in Information Systems

Situational awareness is "perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". The time horizon for these events in air warfare is rapidly changing, as there is a steady shift away from close in weapons. The modern air-to-air capability of air-to-air (Clancy, 1995; Francillon, 2000; Ripley, 1994; Spick, 1995, 2000; Thornborough, 1995; Nordeen, 1999) and air-to-ground systems (Clancy, 1995; Ripley, 1994, 1999; Spick, 1995, 2000; Thornborough, 1995) which makes it is an increasingly demanding environment in terms of the forecasting of future events and interpretation of the current context.

The recognition of the interacting elements of the design equation is crucial to the effective development of battlefield information systems. While the visible coupling of the current context and future events is further apart in imagined space and time; the actual time available for effective corrective action is growing shorter. It may also weaken the ability to link the current actions with the future outcomes and generate more uncertainty. This increasing closure of the intelligence cycle in information systems in terms of time is well illustrated by the use of the JSTARS system or UAVs in the Gulf War to directly guide the actions of forces. An increase in pace and ferocity that has continued with the recent campaigns (Kromhout, 1999).

> "Thus, the J-STARS aircraft, which took radar images of enemy troops moving across the desert from a safe distance, were able to patch their radar pictures directly to the operational fire-control cells in the coalition divisions below, enabling the gunners to select and engage targets at will, without any reference to intelligence." Hughes-Wilson Col. J. (1999) Military Intelligence Blunders. p.349. London : Robinson Books.

This quotation may illustrate a growing tendency towards an increasingly shorter intelligence lifecycle, short-circuiting certain elements of the process. This may be part of an imperative in practical terms to attack mobile targets that can be quickly re-positioned or to use intelligence when it is most effective. These considerations for speed, a vital element of military operations, and the increasingly political need to exert control over the battlefield represent antagonistic forces. There are, however, very good reasons for making "real-time information directly into all cockpits" (Warwick, 1999). The implementation of this information network needs careful consideration to prevent unforeseen consequences at both higher and lower levels.

What makes military information systems vital is the way in which they can shape situation assessment. The highly dynamic characteristics of the modern battlefield require recurrent assessment of the situation to identify problems that are minor and insignificant in isolation but can develop into a major threat (Sarter and Woods, 1991). The continuous process of assimilating new information is cognitively resource intensive and effortful, and the information system must support the process effectively to prevent the operator falling out of the loop or behind the figurative curve on situation developments.

Training Development and Mental Models

Despite the difficulties in measuring mental models it is clear that they play a vital role in guiding behaviour in complex socio-technical systems. Mental models are defined as "an organized knowledge structure that includes objects, situations, and events, and the relationships between them" (Cannon-Bowers, Salas, and Converse, 1993). There is evidence that training can help develop more effective team exchanges and influence team performance (Stout, Salas, and Fowlkes, 1997a, 1997b)

Mental models are important in supporting the third element of Endsley's Situational Awareness, projection of future events. However, mental models may aid the perception and comprehension of events as well. Mental models are products of experience which may or may not be revised, re-evaluated or developed (Rasker, Post and Schragen, in press). It is to be expected that mental models acquire some degree of momentum and as they develop they become more difficult to revise substantially. In energetic terms this may explain the resistance to change a working hypothesis or some more fundamental schema, which has been operational for some time (Gilhooly, 1983).

Cook (2000) has proposed a more elaborate explanation of the typical resistance to change in a model adapted from Rasmussen's (1983, 1986) model of skill development. Rasmussen's model assumes that as a skill develops individuals change their mode or method of processing information from knowledge-based, through rule-based and on to skill-based processing. This model is widely used in the literature to explain the development of skill in the management of complex systems.

Cook (2000) has proposed that emotional and cognitive gradients encourage the skilled operator to try to remain in skill-based mode of operations even though this represents a non-optimal approach to information processing. It is proposed that the experienced operator experience anxiety when they are forced to adopt rule or knowledge-based processing which they interpret as aversive. In terms of a two-factor theory of conditioned avoidance operators are likely to learn that maintaining skill-based processing reduces anxiety induced by feelings of loss of control when they shift to rule- or knowledge-based processing. At the same time the operator will paradoxically feel safer operating in a skill-based mode of processing because they experience less demand on their available cognitive resources. This tendency towards focussed processing among experienced operators has been proposed as a potential contributing factor to accident development and may result in failure to manage more unusual system failures among experienced operators, relative to less experienced (c.f. Huey and Wickens, 1993). The tendency towards less effortful processing has been described many years ago as satsificing (Newell, 1955) but never associated with a model of skilled information processing.

It is likely that both social and cognitive processes are adaptive in complex social technical systems such as that associated battlefield information management (Cook, in press). Recognition of the part played by the team and not simply by the leader, in processing information and arriving at a decision has been strongly emphasized by Artman (1999a). Artman (1999a) has criticized the tendency towards the use of drills in using military command and control systems because of the potential shift towards automaticity of actions. Automaticity can either enhance the adaptability and flexibility, or it can increase the vulnerability of the system depending on the rigidity of the organizational culture. It is important to distinguish the use of drills and training experience in exercises when operators' responses and capability can be stretched or developed. Thus, the decision to engage multi-asset Airborne Command and Control systems in exercises is a very positive step towards effective projection of force in future engagements.

Function of Intelligence Systems

> "not just collection but of collation, interpretation, and dissemination..." Hughes-Wilson Col. J. (1999) Military Intelligence Blunders. p.5. London : Robinson Books.

Battlefield information systems have the potential to capture and transmit large amounts of information. The function of such systems is quite close related to intelligence functions as outlined in Figure 1 showing the intelligence lifecycle. What is not immediately obvious is that the process of delivering information, as in any medium, can result in distortion because decisions may be made about what to transmit to whom.

> "For the professional, intelligence is simply defined as processed, accurate information, presented in sufficient time to enable a decision-maker to take whatever action is required. Hughes-Wilson Col. J. (1999) Military Intelligence Blunders. p.5. London : Robinson Books.

All of the constituent processes can be easily distorted by time pressure and by the application of knowledge. The distortions can be effective exaggerations that reveal the priorities for action or they can be misleading or ambiguous in obfuscating the true intent of the opposition. The important issue is the ability to separate command intent and capability in intelligence analysis. The recognition of error propagation because of inferences and information selection at earlier levels in mediated systems is not new (Mantovani, 1996) and careful analysis of the socio-cognitive aspects of the system requirement need careful development by engaging in dialogue with the stakeholders of the current and future systems. To some extent the recognition of the importance of the intelligence team has been recognized in other domains such as emergency command and control (Artman and Waern, 1999) where the more detailed analysis of interactions has been applied to similar processes.

There are cases where communication support systems, that form a large part of the intelligence network, have decreased the overall levels of cooperation and consensus building, undermining coordination and effective resource management (Wickens, Gordon and Liu, 1998). It is perhaps not surprising that more information can increase the quality of decision making and yet it can decrease the confidence and satisfaction of the group members. According to theoretical model of skilled performance perception proposed in this paper more information could induce anxiety concerning the ability to encapsulate and process relevant information, producing uncertainty. Any individual might deal with a limited part of the information array and as a consequence they might not feel the final decision represents their views effectively. This uncertainty can be managed by organizational or argumentative means. Thus, extending the discussion might help resolve differences as all the relevant items of information are examined in turn and the interpretations and actions considered, or someone may be nominated as the final decision maker who can arbitrate. Arbitration may be a necessary process in time-limited safety or mission critical decision-making in dynamic environment.

Often practitioners forget that battlefield information systems simply reveal a representation of the force disposition and capability of the enemy. This image of the current situation is complicated by the use of enemy tactics such as the use of jamming (Dawes, 1999), decoys (Spick, 1999, 2000), dis-information, and novel strategies.

> "intelligence officers .... who were deceived by the evidence they had so conscientiously collected and collated, and who failed to interpret it correctly- the *misinterpreters*". Hughes-Wilson Col. J. (1999) Military Intelligence Blunders. p.15. London : Robinson Books.

Both the accuracy and spatio-temporal resolution of the imagery is limited by the capabilities of sensors and by the transmission bandwidth available. Thus, the operator in receipt of information must qualify the image by the application of knowledge to resolve the most likely interpretation of the image. Then in the same or in a subsequent process they must infer the enemy intent to establish a course of action. If the operator falls behind the curve in management of their own force disposition or application of their power then the gap between success and failure may narrow substantially.

Intelligence Systems in Team Contexts

It has been noted that same teams operate in variety of situations and coordination of these teams is critically important (Grimes, 2000). There are clearly a number of factors that can be assessed to help ensure the optimal method for sharing knowledge and information across the team.

First, if the timing of information sharing is critical this may determine the way in which information flow is managed and who receives what. Where time is critical, as in air warfare and individual operators are highly skilled it may be better to disseminate raw information more widely. However, the clients receiving the information should have the tools and the display formats appropriate to the task they are required to accomplish as part of the a composite package (Stapleton, 1999).

If timely receipt of information is critical then processing bottlenecks should be identified in all resources, men, cognitive capability and communication linkages. It is all too easy to consider the process of dispatching information as an automatic process and to fail to appreciate the skill involved in selecting, packaging and forwarding information. Only recently it has been publicly announced that JSTARS and AWACS (Anonymous, 2000). This may represent a growing awareness that AWACS and ASTOR, or the U.S. equivalent AWACS and JSTARS, in combination are an effective force-multiplier when crews are trained to use the systems in concert effectively (Anonymous, 1999).

Need to Know

A major issue in intelligence information collected from the battlefield concerns who needs to know and what they need to know. The reasons are numerous.

Knowledge of what one knows can be used inferentially to inject decoys and mis-information into the system to divert resources. The knowledge concerning what is known may indicate the sensor and communication capability of the total information system. By knowing the accuracy of the current image and its weaknesses it may be possible to conduct psychological and information war in which the deployment of resources in strength produces shock or information overloads.
For whatever reason, the use of intelligence information is usually restricted to specific groups. However, this focus on security may lead to under-utilization of the greatest battlefield asset, the distributed and situationally aware cognition of individual operators. No where is this more apparent than in the air warfare environment where small changes in position may change the level of cognitive demand on operators.

Imagine a large package moving across the Forward Line of Troops (FLOT) when the leading aircraft are challenged by the deployment of high capable fighter aircraft travelling fast and high. The lead elements of the package may be focussed on the rapidly advancing threat and modern missile systems bring them within target range very quickly. The elements bringing up the rear may be more aware of Surface-to-Air assets and conscious of the possibility of package elements being forced down into or around onto unseen SAM batteries. If all elements are privy to complete air picture through JTIDS or an equivalent system the response may be more effective. There may be subtle cues to the crews that what is unfolding is a SAM trap and on that basis and briefing they may formulate a more effective plan.

The free availability of the air picture mediated by information distribution on a secure network for all the operators may help to free resources and make the outcomes less subject to the possibility of communication jamming. The cognitive load associated with communication may be diminished and more resources may be available for the specialist roles of the elements of the package. Thus, hard and soft kill EW elements may provide effective cover for the package and the air and ground elements may have the confidence to progress or egress.

Communication is clearly vital in establishing good situational awareness and it has been suggested that free information exchange may help to compensate for limitations within teams (Bolman, 1979; Orasanu, 1990; Schwartz, 1990; Wegner and Simon, 1990). However, communication does not in itself guarantee superior performance (Cook, Campbell and Angus, 1998; Reid, 2000).

The key threat to effective dissemination is the cost of the individual systems making the information available on a secure network and the justification of that cost-cutting measure on the basis of security and prioritization of resources to where it is most required. From the evidence of recent conflicts it would seem that ground, and not the air threat, represents the most potent enemy asset. Both in Iraq and in engagements in the Former Republic of Yugoslavia it seems that that very few opposition forces will be able to effectively mount a coordinated air and ground defence against hostile aircraft for a variety of reasons. However, previous conflicts may not be representative of future operational requirements as the air warfare strategies evolve with knowledge drawn from previous encounters.

There is no doubt that the transfer of information from lower echelons upwards and from higher echelons downwards may create problems and:-

> "It is impossible not to feel some sympathy for those unfortunate commanders who just didn't know, *because someone with the information failed to pass it on.*" Hughes-Wilson Col. J. (1999) Military Intelligence Blunders. p.15. London : Robinson Books.

Misinterpretation can propagate these errors of information omission when higher echelons seek on information confirming their expectations or when lower echelons selectively prioritize information they feel is most pertinent to the current working hypothesis. It is well known that once formed a working hypothesis is difficult to change and it even occurs among those trained to refute hypotheses i.e. scientists (Gilhooly, 1982). The potential for biases and the use of heuristic short cuts in processing large volumes of information are well accepted (Huey and Wickens, 1993). It is possible that these errors may not propagate as effectively when all individuals have access to the raw data.

Capability and Intentions

> "Understanding the differences between a potential enemy's capabilities and his intentions is crucial to understanding the difficulties facing the purveyor of intelligence." Hughes-Wilson Col. J. (1999) Military Intelligence Blunders. p.5. London : Robinson Books.

In warfare it is easy to see the opposition as a monolithic force that one faces and interprets in a coherent way. In the past the strongly controlled Ground-Controller Intercept management of air warfare favoured by the Former Soviet Union was seen as a major weakness. However, no unitary asset on a battlefield can be treated as sharing a common goal of a centralised leadership because it is possible that they have developed alternative strategies. Indeed, the priority goal of destroying the enemy command and control are likely to ensure that the approach taken by different enemy units is likely to be more fragmented and less coordinated or planned. It might be argued that the lack of a decisive policy in Kosovo concerning targets created opportunities for the opposing forces to escape destruction and to ensnare coalition forces in traps (Ignatieff, 2000).

The centrality of leadership, in many frameworks of military analysis, seems to reinforce the tendency towards fragmentation, segmentation and compartmentalisation that may be indirectly supportive a social loafing (Brown, 2000; Hartley, 1999; Latane, Williams, and Harkins, 1979) a phenomenon known to be counter-productive in group interactions.

The important issue in considering these outcomes is the consideration of who is best qualified to interpret the enemy actions, the crew at the front or the fighter controller circling some distance behind the FLOT.

Interpretive Skill and Self-Monitoring

There may be a tendency to focus on certain cues from the developing intelligence in information systems and for this to generate less than optimal performance as a consequence of risky decision making or conservative decision. This tendency has been noted elsewhere in the social psychological literature where faulty decision making based on a risky shift, over-optimism, Groupthink and polarisation (Brown, 2000, Hartley, 1997) are well recognized.

Sir Richard Johns (Chief of the Air Staff) has warned against the possible deluge of information and the slow transfer of information to where it is needed (Penney and Doke, 1999). Sir Richard has stressed that "intelligence must be 100% reliable so that it can be passed rapidly to the targeting and attack systems". This view follows the tenor of the view regarding the use of JSTARS for guiding air-to-ground operations and UAV aircraft for Battle Damage Assessment (BDA) in the Gulf War. Implicitly it suggests that the capture process should reduce the need for interpretive action or information management, that might slow down the process of converting information advantage into tactical advantage.

The dissemination of information is a key issue in the development of battlefield information management systems. The doctrine and policy adopted may significantly affect the performance outcomes and the resource utilisation. It has generally been agreed that there are difficulties in field operations in distributing information and that may be significant in co-ordinating and articulating the different elements of the total force package.

> "It has gotten better, but we still can't get down to the company level what they need to do the job". The coalition forces succeeded in the Gulf, but the contribution of intelligence during the battles was sometimes far from the definition of accurate information passed in a timely fashion to decision-makers to enable them to make correct decisions." Hughes-Wilson Col. J. (1999) Military Intelligence Blunders. p.5. London : Robinson Books

The concerns with distribution of information were echoed in discussions with Stapelton (1999) who suggested that all the elements of force package would benefit from a knowledge of force disposition if it were presented directly to the operator in the appropriate format. It was underlined that the reliance on voice communications for some members of the total package strength was potentially damaging in two ways. First, the groups with better situational awareness (SA) had to work harder to promote SA in the out-group and this added to their workload. Second, those without systems promoting SA were less effectively coordinated and articulated in the package encouraging independent action which was less than optimal in terms of the total battlespace. Thus, the introduction of partial deployment would be counter-productive and may in some circumstances generate greater losses.

The move to deployment of Beyond Visual Range (BVR) weaponry by coalition and opposition assets made information dissemination a priority issue (Kromhout, 1999) . expression of command intent and authority could be muted by the ineffective deployment of weapons systems in an environment where concerns about fratricide and colateral damage were high, as they normally are in peace-keeping, NATO and UN force deployments. The move to beyond visual range weaponry has been accompanied by increasing sophistication of the cockpit environment (Coombs, 1999; Aviation Week and Space Technology, 1996) and the avionic systems supporting the pilot (Gunston, 1990; Rendall, 1997). At the same time the number of operators involved in the system has shrunk to increase the workload on those remaining and this makes team-effectiveness an even more important element of the force equivalent equation. Cooperative and articulated asset use enables higher performance outcomes from the same absolute number of assets and it should decrease risk of losses.

It is clear that no matter how much the system is optimised the operators, in Airborne Command and Control (ACC) systems or in the front-line need training to intelligent execute the actions implied by the interpretation of the information. There is no doubt that the whole process could be automated but the danger would be friendly fire mishaps, colateral damage and political disintegration of coalition forces.

Sir Richard Johns' views concerning the confidence in the information presented are mirrored by concerns from Artman (1999b) who noted that operators who lack confidence in their sensing will either spend time cross-checking the information they receive or they will fail to use it effectively. These domain specific issues are a strong indication that problems concerning trust, confidence and uncertainty raised elsewhere (Thimbleby et al., 1994) are endemic to information systems.

Cook (1999a, 1999b) has proposed that confidence, trust and uncertainty are psychological properties of all physical systems in military usage and they can distort decision making. Given the model presented earlier concerning the strategic allocation of cognitive resources in experienced operators and their aversive experience of uncertain situations, or knowledge-based modes of information processing, it seems possible that strategic management of workload may be guided by affective cues and cognitive resource gradients.

It is surprsing that in complex control situations it may be possible for operators to fail to notice significant differences in the expected and the experienced conditions if the appropriate tools are not available to aid the comparison (Wood, 2000). This suggests that most operators would have only a broad brush impression of the situation and this is confirmed by the analysis of situational awareness in complex command and control situations (Grimes, 2000).

Conclusions

The use of technology to dominate the battlefield is a large part of the most recent conflicts:-

"The second element was provided by computers. When linked up to surveillance satellites as well as spy planes, computers increase the information to the commander and if – a big if – this information can be digested and compressed into timely knowledge of the enemy's dispositions, computers can improve a commander's capacity to react in real time." Ignatieff (2000) Virtual War, London : Chatto and Windus, p. 171.

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Interaction of individual and team performance in ship command centres

Peter J.M.D. Essens
TNO Human Factors
P.O. Box 23
3769 ZG Soesterberg
The Netherlands
Tel. +31 346 356 319
Fax. +31 346 35 39 77
essens@tm.tno.nl

SUMMARY

An assessment of a fully operational command centre performing under high pressures in information load, time stress and cognitive complexity has shown that in particularly, four factors play a crucial role: individual information processing, team management, communication load and the distribution of tasks. It is concluded that individual processes and team processes compete with each other. If individuals are getting loaded then first those tasks will be dropped that are demanding and do not lead towards direct feedback. Team tasks suffer most under these conditions.

KEYWORDS

Command centre, team performance, observational methods, performance evaluation, workload

1 INTRODUCTION

Recently, the Royal Netherlands Navy has launched several studies for the analysis and design of the operational effectiveness of command crew. These aim at understanding better the critical requirements of command centres. An important driver of these studies is the need to optimise crew size and operational performance. In this presentation I will focus on the assessment of the current M-frigate class command centre that was performed in 1998 by a team of researchers of TNO Human Factors.

The attention towards command crew effectiveness is one that fits a gradual development of human factors studies for the Dutch Navy. These had an early focus on workplace ergonomics, and developed gradually into interface design and common visual spaces, into assessment of the human-machine complex in the current command arrangement and for future command centres. In parallel, efforts are being employed to structurally incorporate human factors in the broadest sense into the conceptual development and the design process (Human Systems Integration, US DOD 5000.1, 1992; UK Human Factors Integration Program, D/DOR (Sea), 1991; Beevis, D., Essens, P. & Schuffel, H., 1996).

Command centres

A command centre (operations room, or combat information centre) of a frigate is a typical example of a complex system where information from different 'worlds' (air, surface and subsurface) is gathered, analysed and acted upon.

A command centre can be characterised as a 'human activity system' (Checkland, 1993) designed for human information processing, decision making and execution supported by technologies such as interfaces to sensor and weapon systems, and combat information system. The system is built to respond to a wide variety of situations and signals from external worlds, that are dynamic and change with varying time horizons. The system is complex because it is comprised of multiple people and multiple technologies organised in several subsystems. These have to tune their processes and combine and collate the information produced in order to achieve the mission of the ship.

Traditional human factors evaluations of complex prototypes or operational systems usually focus on operator performance instead of performance of the whole system (Meister, 1998), or limits evaluation to a sub-system, such as the human-computer interface, or to a single criterion, such as workload. Outcome measures of the whole system may be used to get an summative view on the performance of the whole system (often referred to as MOEs). The problem is however that a systems outcome approach treats the system as 'black box' (input-output) hiding multiple internal sources of positive and negative effects which lead to some composite

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result. Therefore these measures fail to provide an understanding of the factors that generate that outcome. The fundamental problem however is that there is still insufficient knowledge of the contribution of one factor to the outcome of the whole system or what factors contribute most.

2 M-FRIGATE COMMAND CENTRE

The study of the current command arrangements in the M-frigate - the focus of this paper - was driven by the Navy's need to understand better which factors are critical for effective performance in order to optimise *current* command and to incorporate those in the design of *future* ship and command centres.

A command centre in full operation usually displays an impressive hectic and concentrated activity often with intense verbal communications via networks and face-to-face. Assessment of performance under these conditions requires a well developed methodology and instruments that capture the dynamics of the processes and addresses the critical factors of the complex system. Our tasks was to develop such methodology.

Of other studies in Naval command, in particular the TADMUS studies should be mentioned (Cannon-Bowers & Salas, 1998). Similarly to goals in our command studies they study the complex nature of command in dynamic and stressful situations. A difference is that they have focused on the air defence team, while we look at the command centre as a whole representing the mission of the ship.
Moreover, the M-frigate assessment was directed specifically to the factors that determine effectiveness of the current command centre. This will then be used as a baseline for further studies. The assessment does not address the strategic or tactical outcome of decision making, nor the performance of the technologies used, rather it focuses on individual and team processes in information processing and decision making.

Performance indicators

High workload conditions are considered to be 'normal' in an operational command centre. The question is whether workload levels are that high that processing capacity, of individual or team, shows its limits. This would negatively affect performance effectiveness – there is more to be done than can be handled in the time given. A second question is whether workload is evenly distributed over the crew. If in a critical situation some team members have not much at hand while others are overloaded, then resources are apparently under-utilised. But, not only from an operational perspective is workload an important issue. Also for the crew's appreciation and quality of work: constant performing below expectations will result in negative feelings and consequently in lower performance.

In dynamic event-rich situations measuring workload once at the end of a mission would be insufficient. A continuous review of the workload gives insight how workload develops over time for each crew member, where bottlenecks are in processing capacity, and how workload is distributed over the crew members.

Workload can be used as an indicator of efficient and effective team performance but does not show how well the job is done. Qualification of how well a task is being performed requires insight in how the demands of an operational situation are addressed. In complex tasks one should also take into account that there are parallel tasks to be processed and prioritisation or effective task switching can only be judged in context. This is the role of the domain expert. Judgement of quality should be coupled with critical events in the scenario's which makes it easier to score during a sessions.

METHOD

Experimental setting

Obviously, in order to assess the effectiveness of a command centre under critical conditions one needs a realistic setting, with realistic scenario's, with a team that is fully operational.
On the other hand, for producing well-founded conclusions, one needs control over the situation, repeated measurement using multiple teams responding to the same situations. Moreover, given time and resources available this has to be done in an efficient way.

We have used the Navy's training facility which has a copy of the M-frigate command centre. The use of matching equipment and layout facilitates the application of skill-based activities so that the teams can perform the way they are used to; only the variations in the scenario's will show in the performance.

The use of a land-based facilities always evokes discussions of the effect of ship movements on the performance. Indeed, ship movements result in fatigue which affects performance. Moreover, there may be effects on team tasks such as communication and team management. A second aspect of reality not easily simulated in a training facility (and in standard sea-based exercises) is the stress of being under attack. It was argued that these factors would certainly add to performance degradation, but that first stress due to time-limits and information-uncertainty should be investigated. In order to augment the validity of the assessment, the findings from the experimental situations were verified during full sea exercises.

Registration of workload

All workstations were equipped with a special keypad with five keys representing a 5-point scale: Most left key represents score 1 defined as 'time left'; most right key defined as score 5 indicating 'too little time'. The middle key (3) was defined as 'just enough time'. The operator's task was to indicate how much time was left for doing their jobs at that very moment. Every five minutes a small lamp on the keypad flashed which cued the team member to give a judgement. Each key press was registered in a computer-system and linked to video registration (Observer system).

Registration of performance quality

Four indicator categories are distinguished: the quality of the information processing of individual crew members, the communications between the team members, the handling and application of the systems and tools, and the management of team by the team leader. The categories cover several subcategories:

- 'Information processing' comprises delay in information processing, overlooking of information, errors in interpretation;
- 'Communications' concerns the correct application of communications procedures, timely communications, interrupting communications;
- 'System handling' covers the ease of operating a system, lack of skills in operation; adequacy of settings;
- 'Team management' refers to limitations, adequacy or overdoing in direction and control.

Seven domain-experts were distributed over the team and observed performance. When they judged during the session that one or multiple categories were applicable in that situation this was scored on a form and with a key press the instance and its weight was linked to the video recording.

Scenario's

Scenario's are sequences of predefined conditions and events. Assessment of a system requires critical events of combination of events that load of even test the limits of the central functions of a system. For a command centre central functions are processing information and making decisions. Three scenario's were developed: a normal workload scenario's of which was expected that a well-trained team could handle without problems; an input information-load scenario with many tracks and information units; and, an information-uncertainty scenario with missing information and unexpected behaviour of the objects in the world.

Scenario design was based on our knowledge of factors that affect information processing and decision making, such as:

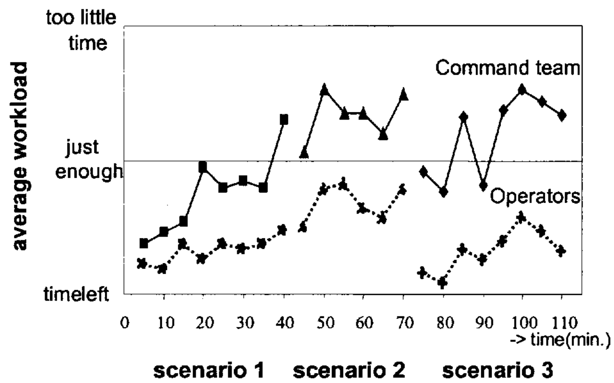
- number of tracks and multiple threats or targets, and number of potential measures relate to overload of information handling;
- conflicting information, ambiguous cues, threats, multiple options and criteria, conflicting use of resources relate to cognitive stress and processing capacity;
- insufficient information, misleading or novel situations, limited feedback relate to availability of knowledge and experience.

Procedure

Four experienced and fully-operational teams of 16 members each participated in the assessment sessions performing in three scenario's. At the start of the session they received a standard operational briefing which explained the operational situation and mission. Also was explained that measurement tools were used to get an indication of the functioning of the command centre and that no individual scores were isolated. The scenario sequence was the same for each team: normal, information-load, information-uncertainty scenario. Each scenario took about 40 minutes. Between each scenario was a break. After the session a questionnaire was handed out which addressed the functioning of the command centre on board. Subsequently, in a debrief scenario events and typical performance, actions and decisions were discussed by the team.

RESULTS

Workload data showed that about half of the scores are around the middle level ('just time enough') which can be considered as the standard level of load during operations. One third of the scores was below that level indicating that there was ample time for performing the tasks at hand. One sixth of the scores are above the just enough level indicating that there were instances that there was very little time to perform the task at hand. Overall levels of the scores can be clustered around subgroups in the command centre. It was found that the command team has on average a higher workload then the supporting operators, with exception of a particular subgroup of operators (the electronic warfare operator and controller) who had also a high workload. There was little difference between the two test scenario's. The conclusion is that the unequal distribution of workload found results from an organisation of tasks which, under complex conditions, centralises control with the command team.



Quality assessment of performance showed several opportunities for improvement. Of most interest is the distribution of the scores over the categories. The domain experts particularly judged that team direction and control (35%) and individual information processing (30%) could be improved; less prominent were system handling (18%) and communications (17%).

The questionnaire showed that internal communications was considered to require a high level of attention (90% of respondents, N=53), and that its volume was considered to be too high (60%). The tasks to be performed are in general time critical and require high attention (88%). System handling could be improved by improving the interface with more direct interaction. In time critical situations any system delay is considered hindering performance.

DISCUSSION

The assessment of the command centre performing under high pressures in information load , time stress and cognitive complexity shows that in particularly, four factors play a crucial role: individual information processing, team management, communication load and the distribution of tasks. An interesting statement from a Naval evaluator describes the combination of these factors most adequately: 'when load increases in the team curtains seem to get shut between team members'.

In trying to understand the combination of factors we distinguished between the structural settings of the command centre and the command and control process itself. Structural is the given quality of the team and their ability to work together. Structural is the distribution of tasks and the work procedures that are predefined. Structural is also the technology used to support or enable the command centre to do its job. These factors are brought into play before the mission starts.

During the operations people are the flexible and vulnerable force and adopt compensation strategies for what is structurally imperfect: a situation most people recognise immediately. From the literature on stress handling a checklist of strategies was derived (Gaillard, 1996):

- first people try to compensate for situations the system was not designed for by putting extra effort into play
- if load rises further tasks for which that is possible are delayed or postponed
- subsequently, focus is on a limited set of tasks; at best the central and most critical tasks
- less communications is observed with an increasing tolerance for errors (correction costs time and effort)

- finally, control over other people is loosened and eventually lost.

This list shows the process that can also be observed in highly loaded conditions in command centres. It shows that individual factors and team factors interact with each other in an understandable way. If individuals are getting loaded and then first those tasks will be dropped that are demanding and do not lead towards direct success or hinder their most direct responsibilities. Team tasks can be considered to be such tasks. In particular when team leaders have also other tasks than direction, control and co-ordination the danger is that they will do the direct accountable tasks first and postpone other tasks to later. Eventually this may result in a breaking down of the team as a whole.

In conclusion, the following factors are considered critical for effectiveness:
- Organisation of processing capacity: focussed on optimised task distribution; flexibility in task allocation; reduced communications
- Quality of people / team: focussed on training as a team; training graceful degradation in order to deal with overload situations; training in complex and varied situations
- Technology: focussed on directness in interaction and response; support in handling information.

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A research framework for command centre teams

Peter Christian Rasker & Wilfried Maria Post
TNO Human Factors
P.O. Box 23
3769 ZG Soesterberg
The Netherlands
Tel. +31 346 35 62 60
Fax. +31 346 35 39 77
Rasker@tm.tno.nl

SUMMARY

The effectiveness of a command centre largely depends on the effectiveness of the team that keeps it going. This paper describes a framework of five research methods to investigate command centre teams. These methods comprise modelling, observing, experimentation, design, and evaluation. *Modelling* implies breaking up a whole human-human-machine system into essential elements. It is an analysis resulting in a clear description of the system. *Observation* is needed to identify possible bottlenecks in the command centre. It yields insight in the composite set of factors that influence the effectiveness of the command centre team. Single factors can be investigated systematically by *experimentation* using a contrived experimental task. The knowledge that is gained by modelling, observation and experimentation can lead to the *design* of a new command centre team, or the redesign of current ones. Finally, any particular design may need an *evaluation* to determine how team performance is effected. The application of the framework is illustrated by a number of research projects.

KEYWORDS

Command centre, teams, research methods

1 INTRODUCTION

The ability of teams to work effectively is a prerequisite in a number of critical work environments, including military command centres, fire-fighting, aircraft cockpits, emergency medicine, and air traffic control. Such teams often have to perform in complex situations that are characterised by time pressure, heavy workload, ambiguous information presentation and a constantly changing environment. High stakes are involved and poor performance may lead to considerable consequences.

Many studies demonstrate the importance of teamwork. For example, in the aviation domain several studies have shown that many incidents and accidents are due to miscommunication of the flight crew (Helmreich & Foushee, 1993). The accident with the *USS Vincennes* has been attributed to ineffective teamwork (Klein, 1993). Heath & Luff (1992) show that effective crisis management in the London underground line control room depends on how operators exchange and monitor information. Finally, in the medical world, ineffective teamwork has led to a considerable number of incidents in anaesthesia (Howard, Gaba, Fish, Yang, & Sarnquist, 1992) These studies show the importance of investigating teamwork to identify the factors that makes a team effective.

The focus of this paper is the research on command centre teams. A command centre team is defined as a set of at least two people that work together toward a common goal, who have been assigned to specific roles or tasks to be performed, and where the completion of the mission requires dependency among team members (Dyer, 1984; Salas, Dickinson, Converse & Tannenbaum, 1992). Central in our approach is that the command centre is viewed as a complex cognitive system in the sense that it takes situation specific information, knowledge from training and experience, mental constructs (hypotheses and assumptions), and norms and values that are combined into new information entities (Essens, Post, Rasker, 2000). The core-business of a team in the command centre is information. Signals, datalinks, intelligence and so forth must be received, interpreted, and assessed in order to decide upon the righteous action. Because tasks, information sources, and expertise is assigned to different team members, interdependent interaction is needed. This interdependency requires team members to engage in teamwork behaviours such as communication and co-ordination. The challenge is to determine how effective teamwork can be realised in complex systems such as the command centre.

The appreciation that teamwork must be seriously studied is shown by the variety of research questions that come from practice. A first type of question is related to the complexity of a command centre representing a need for a clear description and understanding of this human-human-machine system. Questions such as, "which tasks are performed and which knowledge is needed" and "what is the information flow in the command centre and how is this exchanged by team members" represent this need. A second type of question arises out of problems that are experienced in practice. Often there is a vague idea that something is wrong, but one cannot lay hold on the specific bottlenecks and the seriousness of

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bottlenecks. This is represented by questions such as "are there problems with the workload?" or "do we train our personnel well enough?". A third type of question comes from a need to develop a deeper understanding in the underlying factors. Questions such as "which type of knowledge is needed to communicate efficiently" or "what is the effect of cross-training on co-ordination" represent this need. A forth type of question is associated with the design of new concepts, systems or layouts. This is represented by questions such as "how must the command centre be equipped" and "what is the best layout of the command centre to support effective human-human interaction". Finally, the last type of question arises from a need to evaluate whether the designed concepts, systems and layouts are applicable and effective in the real world.

The objective of this paper is to describe in a framework how several research methods can be applied to investigate command centre teams. These methods are used to find answers for the various types of questions stated above. With these methods, teamwork can be investigated in command centres as well as in any other complex human-human-machine system. We will illustrate the framework with a number of research *projects* and research *techniques*. First the framework as a whole is explained, and then each method is discussed separately.

2 RESEARCH FRAMEWORK

For investigating team effectiveness in complex systems we describe a research framework consisting of five complementary, but individually applicable, methods that span all phases of team research and development. The five methods are modelling, observation, experimentation, design, and evaluation. Figure 1 presents this research framework.

Modelling is needed for gaining understanding of the complex environment in which the team has to operate. Modelling yields a description of the essentials of a team, such as its *structure*, the links with the broader *organisation* in which the team has to operate, the *functions* that has to be fulfilled, the tasks that the team members have to carry out, the *knowledge* they need for that, and the types of *information* that flows within the team. The resulting team model provides the set of descriptors for all team entities that are subject of further team research and development. Once the team is well enough understood, one is able to make a useful observation of an operating team. *Observation* deals with the actual team process, revealing a problem description in terms of possible *bottlenecks* and *challenges* for improvements. During observations, many facets play a role at the same time, and linking a problem to (*interaction* of) particular *factor* is not always possible. With experimentation, where a team environment can be controlled, the contribution of separate factors for team effectiveness can be identified. New initiatives, or observed bottlenecks and challenges in an existing team lead to team (re)design. Design encompasses the application of all factors of team effectiveness (known from own research as well as others) to new *concepts* and detailed *realisations*. Finally, a designed team may be evaluated to acquire objective team performance measures in terms of *speed*, *workload*, *quality*, and *quantity*.

Each method has a set of research and development techniques associated to it. The next sections describe de application of each method in several projects, and how they are supported by the available techniques.

3 MODELLING

The functioning of a command centre team is not easy to understand. For an outsider it probably seems like magic

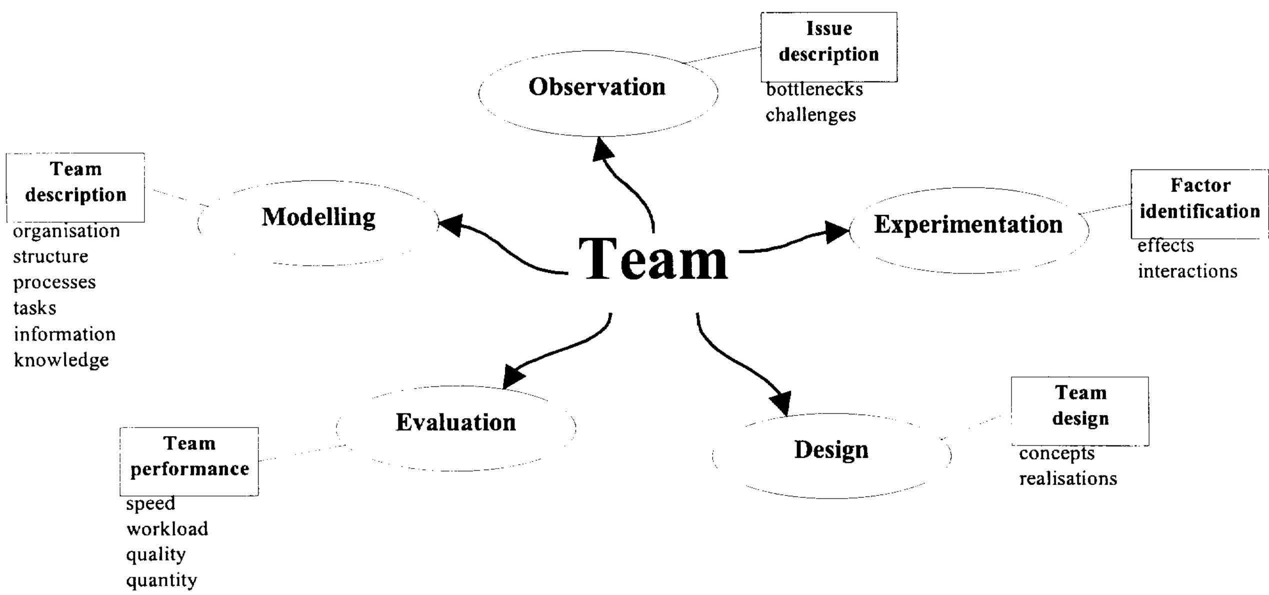

Figure 1: Research framework for team research and development

how a team does its job, using an overwhelming amount of displays, push buttons and communication equipment, communicate with strange abbreviations, being quiet at one time, and completely occupied the next moment. The purpose of modelling is to develop an understanding of this complex team and its environment. This is done by reducing its complexity through an analysis and description process. By analysis, the whole system is broken up into its essentials. This is a complex process itself, because the essentials and their relationships are not readily given. Often, they have to be abstracted from the many details, and the abstract entities that arise need to be labelled and described. By doing so, modelling provides a clear *team description* and an easily accessible "map" of the command centre team.

There are many ways to model a team. In our approach we distinguish nine so-called team modelling perspectives (Essens et al., 2000). These are an organisational model, a function model, an information model, a function-information model, a human agent model, a technical means model, a knowledge model, a task model, and an event handling model (See figure 2). The organisation model shows the relation of the team within the broader organisation. The function model shows the command centre functions hierarchically. The information model shows the information that is used and processed in the command centre hierarchically. The function-information model shows the information dependencies of the functions on the different hierarchical levels. The agent model describes the team member roles; the technical means model the equipment that team members have to their disposal. The task model takes the end nodes of the functional hierarchy and couples these with the end nodes of the information hierarchy (as input and output), the technical means, agents, and the knowledge entities as controls. Finally, the event-handling model shows the response to a tactical event in a temporal sequence of functions that are distributed over agents.

By using a hierarchical approach in modelling, we are able to finish at any hierarchical level and still have a complete description. If necessary, specific end nodes of the hierarchy can be modelled in more detail when bottlenecks are experienced (or established by observation) in that part of the hierarchy.

Project

This method is applied to model the command centre of the Royal Netherlands Navy (RNLN) multipurpose frigate. Knowledge about the task-related structure was elicited from domain experts during group sessions. This forced the researchers to specify precisely their understanding of the system. The large quantity of information (changes, annotations, new branches) elicited in the group sessions was difficult to process afterwards. Because the models are strongly interrelated, adapting them became a major effort. For future modelling efforts, further technical support is needed for consistency checking, glossary update, version management, and for having navigational overview within and between models. Overall, this provided us with approximately 400 interrelated graphical representations implemented with a browser on CD-ROM.

Techniques

The first technique applied in modelling is *document analysis*. We gathered various documents, built a glossary of the terminology found, and, after having studied the material, we started with representing our own mental model of the human-human system. Next, we developed a *visualisation* technique to describe this mental model, first for communication among the researchers. We used a representation language and graphics in the models consisting of a restricted set of descriptors with a consistent form and a consistent meaning. For example, in figure 3, an arrow means data

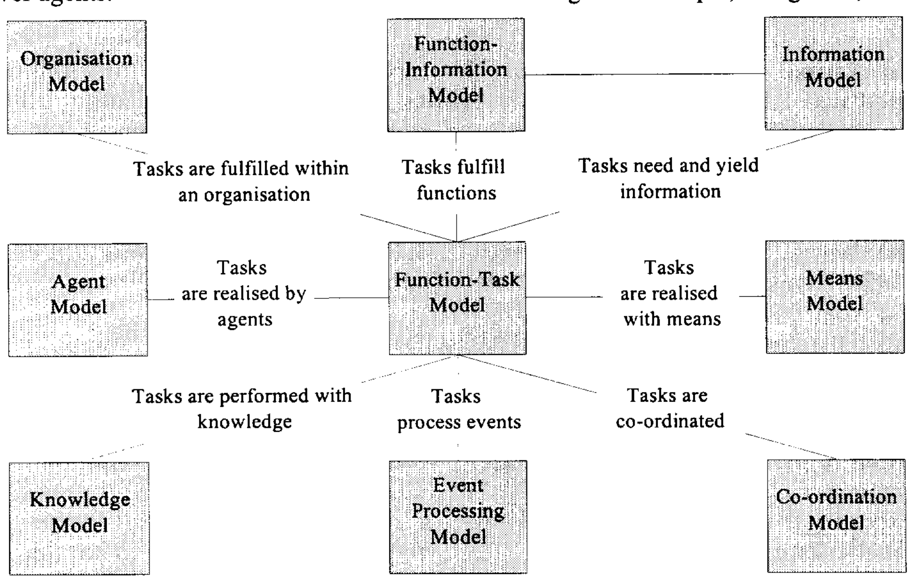

Figure 2: Suite of models for the description of a complex system

dependency, a small-circle with a line means a part-of relationship, a rounded box represents a function or task, a square box represents an information entity, and knowledge is represented by a square box with a line, After this preliminary description, we used the graphical model as a means for *interviewing* the domain experts. Because many subjective perspectives arose with the various experts we interviewed, we finally asked other, senior, experts, to give the models an official status, a technique we called *standardisation*.

4 OBSERVATION

Observations are needed to give an answer to the questions that arise out of problems that are experienced in practice, but were one cannot identify the specific *bottlenecks* or the seriousness of these bottlenecks. It concerns an *issue description* in order to develop insight in the *challenges* to improve team effectiveness. With observation we mean a systematic analysis and on-line measurements of the ongoing process of team

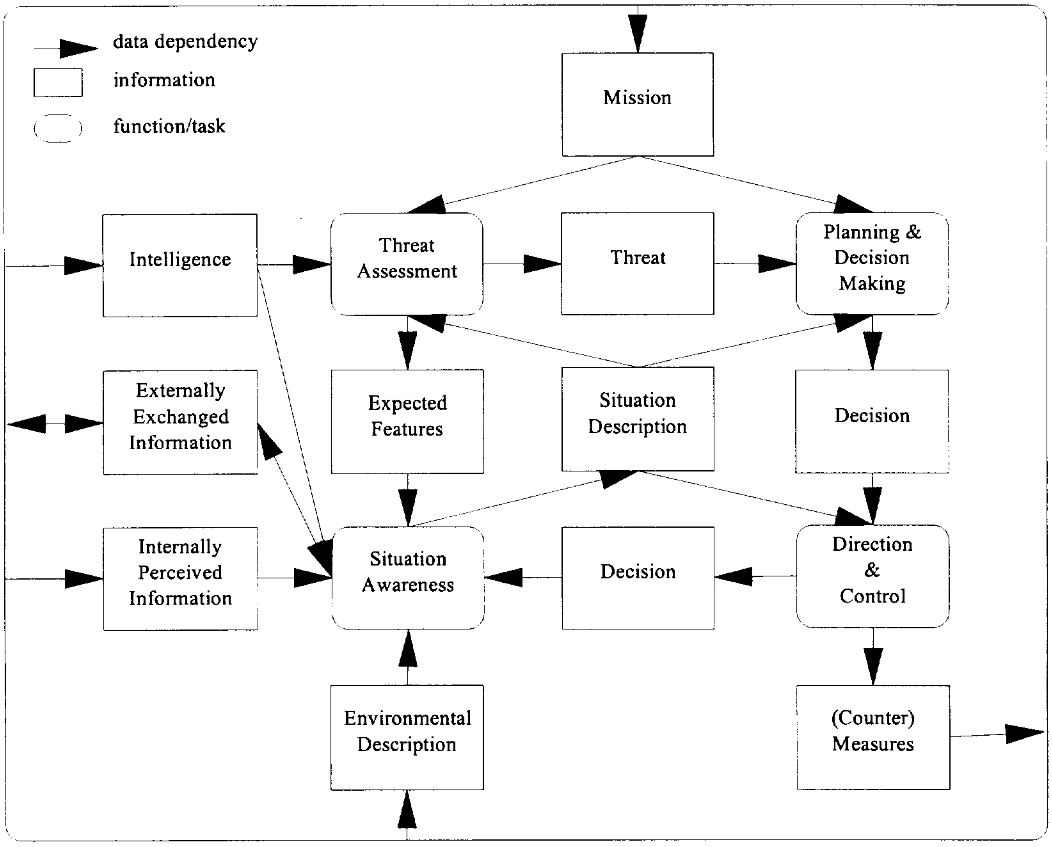

Figure 3: example of one level of the function-information model

Figure 3 shows an example of the used representation language for the function-information model. This example describes Command & Control at a generic level (Passenier & van Delft, 1997). The functions are linked with their information input and output entities. The diagram shows the data dependencies between the functions. *Situation awareness* consists of a permanent process of compilation, monitoring, and maintenance of the actual situation. Outside information and internally perceived information (i.e., from own sensors) is used to develop and maintain an actual situation description. This information is used for *threat assessment* by interpreting the current situation from a tactical perspective. *Planning & decision-making* is performed by selecting options and planning (counter)measures. The decision is executed during *direction & control* by giving directives and allocating resources.

functioning in its natural setting. This provide insights in the effectiveness of the command centre team and reveal possible bottlenecks concerning individual task performance, communications and information exchange, co-ordination, workload and so forth. This insight is needed to solve the experienced problems either by designing a new system or by adjusting the current system.

Project

Observations are performed to investigate the command centre of the RNLN multipurpose frigate (see, for an elaborate description, Essens, this volume). Four operational command centre teams performed three realistic warfare scenarios (e.g., *baseline* normal pressure, time pressure from handling multiple objects, uncertainty form object behaviours) in a simulated command centre trainer with a duration of three hours including operational briefing at start shift. Seven domain experts strategically distributed over the team members' positions determined systematically the performance quality. During task execution each team member produced a workload score. A questionnaire completed data collection. In a debrief session a selection of the observations were discussed with the experts, the investigators, and team members to get more insight in the background of particular actions and decisions. Based on these observations it was concluded that in times of stress own task responsibilities dominate and push away teamwork responsibilities despite the generally strong emphasis on total team performance.

Techniques

To observe systematically, three techniques are developed to measure performance: a *quality indicator sheet*, a *workload registration tool*, and a *task-performance questionnaire*. In addition, task performance is registered digitally on video (including audio) that is used for reviewing.

After a pre-briefing about the content of the research, performance is measured during task execution. Domain experts (e.g., operational experienced officers) score the *quality indicator sheet*. Each time a problem is scored, the experts also push a button that results in a time registration linked to the video stream. This is used during the review to the find easily the video data that is linked to the scored problem. Workload is measured with the *workload registration tool*. This specially designed button panel consists of five buttons. The buttons correspondent with a five point scale that each measures a degree of subjective workload. The registration of the subjective workload takes place every five minutes. The button panels are linked to the video stream that registers the measurements.

Afterwards, the team members fill in the *task-performance questionnaire*. In the meantime, the domain experts and the researchers review and discuss the task performance based on the scores on the *quality indicator sheet*. During this review it is determined which observed problems are the most critical and need to be made more explicit. Subsequently, the domain experts, the researchers, and the team members discuss these problems to develop a deeper understanding of the underlying causes. When needed, the video data are showed to explicate. All together the experts' scores, the workload measures, the questionnaires, and the discussion reports form the data from which conclusions about the observed problems are drawn.

5 EXPERIMENTATION

Observation yields insight in the composite set of factors that influence the effectiveness of the command centre team. From observations, however, it is not clear to what extent single factors may affect team effectiveness. Therefore, we investigate single factors systematically by using a contrived experimental task in the form of a low fidelity simulator. With the help of such a task we attempt to *identify factors,* and develop an understanding of their *effects* and *interactions*. There are several advantages for using a low-fidelity simulation (see also, Bowers, Salas, Prince & Brannick, 1992). First, the methodology is available at relatively low cost. Second, it gives opportunities to develop the characteristics needed in team research. Third, it provides the requisite experimental control of independent variables. Finally, it is relatively simple to train team members, which makes it possible to invite naïve participants in stead of operational team members that are difficult to recruit.

Project

Experimentation is used to investigate the effect of intra team feedback on developing shared mental models in Command & Control teams (Rasker, Post & Schraagen, in press). Team members that share mental models, are expected to have common expectations of the task and the team, allowing them to predict the information needs of team members accurately. This makes it possible for team members to offer each other the necessary information at the right moment, which results in an improved performance. It is hypothesised that intra team feedback plays an important role in adjusting and developing a shared mental model. By giving each other feedback, team members develop an understanding of each other's tasks that gives them insights in which and when information must be exchanged. A distinction is made between performance monitoring and team self-correction. Performance monitoring is the ability of team members to monitor each other's task execution and give feedback during task execution. Team self-correction is the process in which team members engage in evaluating their performance and determining their strategies after task execution. In two experiments, the opportunity to engage in performance monitoring respectively team self-correction was varied systematically. The results show that teams perform better when they have the opportunity to engage in intra team feedback. Both performance monitoring as well as team self-correction appeared to be beneficial for team performance.

Techniques

One complicated factor of studying teams using a low-fidelity simulator is that the generalizability to real-world environments is limited. We tried to reconcile this by developing an experimental team task that contains the activities, processes and situations that are typical for Command & Control teams. Based on a generic Command & Control model we performed a task analysis using the previously described modelling method that provides not only a task hierarchy but also describes the information dependency between tasks, the knowledge needed to perform tasks accurately, and the sequence of tasks for each team member. Based on this task analysis we specified the different roles and expertise of team members and the information dependency between them. In addition, by showing that the specified tasks have to be performed in parallel, we demonstrated that the experimental task is a task for two team members, which cannot be performed individually. Based on the task analysis, we attempted to develop an experimental team task that contains the advantages of low fidelity simulations but still can be generalised to real-world environments.

The experimental task we developed is a low-fidelity simulation of a dispatch centre representing a fire-fighting organisation in a city (Rasker, Post & Schraagen, in press). The fire-fighting team, consisting of an *observer* and an *allocator*, is required to fight fires in order to keep the number of casualties as low as possible, which is the goal of the task. In order to accomplish the goal, the observer has to assess the city and inform the allocator about the status of the buildings. This is comparable to the situation assessment function in Command & Control. The allocator has to allocate a number of resources (i.e., fire-fighting units) to the buildings to extinguish fires. This is comparable to the function of decision-making and taking counter measures in Command & Control. Because the number of units is limited, the team must prioritise and decide upon which fires they want to extinguish. Team members are interdependent of each other. This means that they are required to interact continuously about the status of fires and the resources to accomplish the goal.

6 DESIGN

One part of the development of a new human-human-machine system, such as a new platform, is the design of certain team organisations such as for Command & Control, navigation, and ship control. *Team design* can be at a *conceptual* level (e.g., a proposed task organisation) or a can be a *realisation* at a detailed level (e.g., the layout of a command centre). A team organisation may be redesigned, when bottlenecks or challenges are observed in an existing team. In a design process, the known team factors are applied to new team concepts and actual working teams.

In designing a human-human system the following phases can be differentiated (Beevis, Essens and Schuffel, 1995):

- Defining the mission of the overall system
- Establishing the functions that need to be fulfilled
- Determining the tasks that need to be carried out
- Determining the required manning and means
- Job design (task allocation)
- Workplace design

Project

The design process is illustrated by the development of the command centre of the Air Defence and Command Frigate of the RNLN. The first phases of the design process were already established by the RNLN: the mission to establish the functions to fulfil the number of agents needed, the choice of equipment, and job design. Our role in the design team was to design the workplace (Post & Punte, 1997; Post & Punte, 1998).

From the literature and our own research, a number of factors for team effectiveness were identified:

- shared mental model (Cannon-Bowers, Salas & Converse, 1993)
- non-verbal communication (Fussel & Benimoff, 1995)
- adaptive co-ordination (Entin & Serfaty, 1999)
- situation awareness (Endsley, 1995)
- intra team feedback (Rasker et al., in press)
- team training (Salas et al., 1993)

From these factors, and the design decisions made by the RNLN in the earlier phases, two concepts on team support (as well as other aspects, such as technical and economical feasibility) were generated and assessed. Both concepts had a number of aspects in common that already were an improvement to the most recent command centre that was designed for the RNLN, such as the use of large screen displays for deliberation support, and a briefing room for training support. One concept was a traditional one, based on the most recent command centre that was designed: consoles placed in three rows, the middle one the command row, the row in front the picture compilation and weapon employment row, and the row in the back the support row (e.g., communication support, equipment support, network support). In the other concept, the traditional way was left and the rows were placed in a circle. We found that in a circle, the mean distance between team members was shortest.

The second rounded concept proved to be the best at the aspect of team support. For individual work conditions, however, the rounded concept was unacceptable due to adverse ship motion effects (Bittner & Guignard, 1985). Nonetheless, a number of principles for this concept were taken over. This led to the final conceptual design, with large screen displays and an integrated briefing room, that was optimised for frequent and critical interactions (i.e., putting those people near each other who need to work in closest co-operation). Further, visual deliberation and supervision lines at larger distances could be optimised by placing the individual work places nor in a row, neither in a circle, but in a kind of wave form.

The next step was to translate the conceptual design in a detailed design. At this stage, we made a full scale wooden mock up of both the individual work places and the complete command centre, and invited in total 75 future users to assess the design (among other aspects) on co-operation, deliberation and supervision support. Based on this finding the command centre was redesigned and approved for realisation.

Techniques

In designing the workplace, we used a number of techniques:
- link analysis
- drawings
- scenarios
- physical mock-ups

In RNLN example, we only designed the workplace of the command centre. Currently we are carrying out research for the RNLN future Command & Control, in which we also design reduced command centre teams, including team size, necessary means, and job design.

7 EVALUATION

The ultimate goal of modelling, observation, experimentation and design is improving the effectiveness of *team performance*. Evaluation stands for determining and verifying this effectiveness. Two types of measures are important for team effectiveness: process measures and outcome measures. Process measures refer to *speed* and *workload*, and outcome measures to *quality* and *quantity*.

Project

Evaluation is not only possible at a final stage, when a design has been realised. In the command centre example provided above, we used a wooden mock up for evaluation purposes, and had RNLN personnel perform a scenario. We asked them to fill in a questionnaire on team aspects. The questions were about the positioning of their co-workers, how the command team was able to deliberate, how supervisors could view their personnel from their positions, and how they could communicate non-verbally. We let them compare seven row configurations (such as a straight row, an indented row and a waved row) on the team aspects mentioned above. Moreover, we made this comparison for three different individual work places: one with a single screen, one with two 20" screen, and one with a primary 20" screen and a secondary 14" screen, making up 21 (7 times 3) configurations. We could find at statistical significance level how type of row and type of individual work place relate to team aspects. Figure 4 shows some of the configurations of rows.

Another evaluation example is obtained from the SmartStaff project (see, for an elaborate description, Post & Hamaker, this volume). The aim of this project is to find the best team support for the Task Group Staff. This staff is embarked on board of the Air Defence and Command Frigate, and has its own Staff room. In contrast to the command centre and the navigation bridge of this frigate, the RNLN had no clear vision on how to equip the staff room. Therefore, we took it as a research challenge to come up with a support concept for team planning, which is the main task of the Task Group Staff. The resulting concept, called Smartstaff, supports the team with:
- both individual and shared work spaces
- flow and storage of electronic information
- a common focus of attention
- concurrent idea generation

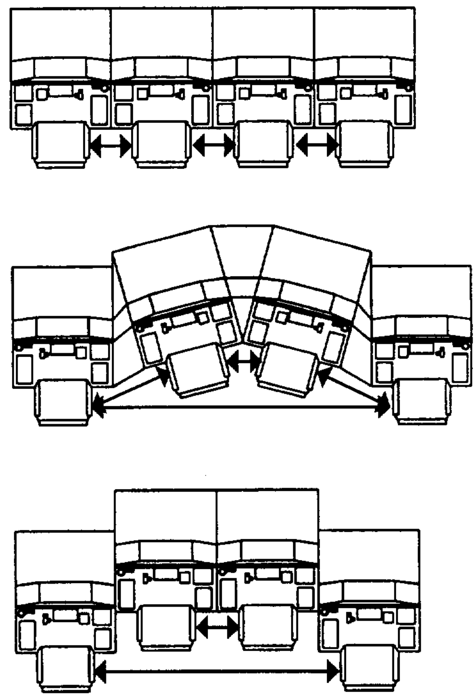

Figure 4: Configurations of rows. The arrows show some lines of views

SmartStaff has been evaluated by using a staff room mock-up with for each team member an individual workstation and two large interactive touch screen displays, electronic storage, retrieval and exchange of information, and an electronic idea pad: a tool for both individual and team generation and representation of ideas. To guarantee face-to-face contact and an unlimited view of the large screen display, the workstations were lowered and positioned in a semi-circle around the large screen display.

Our aim was to carry out a conceptual evaluation. At an early stage, we wanted to know whether our concept was profitable, without having to implement the concept fully. We were able to reduce the software development effort to a minimum, by using existing software as much as possible, and letting the integration efforts (often the most expensive parts of software development) over to the evaluators, who had therefore to strike some extra keys during the evaluation session.

In this evaluation session, all 14 RNLN Task Group Staff members, including the Commodore, served as subjects. They were first asked to fill in a questionnaire about their current staff room. Next, they had a one-hour training in using the SmartStaff environment. Then, they were provided with a realistic scenario in which they had to plan a journey for the Task Group. After that, they had to fill in again a questionnaire, but now about SmartStaff. Having experienced this new task environment, the evaluation session concluded with a group discussion. During the session, an external observer, who joined the Staff earlier, assessed the team as well. It was found that SmartStaff provides better support on the unambiguity of the shared picture of a tactical situation and the plan itself, on time management, and on presenting and communications of ideas and plans. The quality of the plan was not influenced.

Techniques

Summarising, the techniques used in both studies are:
- hardware and software mock-ups
- Questionnaires
- Scenarios
- External assessor
- Experienced group discussion

8 SUMMARY & CONLUSIONS

Effective teamwork is a prerequisite in a complex system such as the command centre. Investigating teamwork and determining what makes a team effective is a great challenge for team researchers. The objective of this paper is to describe in a framework how several research methods can be applied to investigate command centre teams. This framework helps to place the questions that come from team practice in the set of methods and techniques that are currently available. The research framework that is proposed comprises five methods that cover all aspects of team research: modelling, observation, experimentation, design and evaluation. For each method, the research framework was illustrated with a number of projects and the techniques Table 1 gives an overview of the methods, matched with the questions for the specific projects, the used techniques, and the results.

Matching the questions to the methods makes it clear, in our opinion, which research effort is possible to provide usable answers. This serves as a guidance to make a choice between the methods available. Although the methods are treated separately, they are related with each other. Most important is that they all contribute to our knowledge of how teams perform and which factors make teams effective. This knowledge is used to modify and refine the research techniques and give direction in our new research efforts. Moreover, this knowledge is used to develop new concepts and realisations for optimising team effectiveness. We conclude that the research framework provides a useful overview of the methods one can apply to investigate command centre teams. Each method can be used to find an answer to a part of the puzzle how to optimise effective teamwork. In total, the research framework represents an integral approach for investigating command centres teams that should lead to an answer of the complete puzzle.

For future research concerning team effectiveness in the command centre, all methods will be applied. *Modelling* will be applied to describe the command centre of the new mine counter measure vessels of the RNLN. In addition, we are planning to elaborate our modelling techniques in order to simulate team behaviour in Command & Control situations. This way we are able to use modelling not only for description but also for *experimentation.* Different factors will be modelled in order to investigate their effects on team effectiveness. Furthermore, we will *design* a concept for improving the briefing sessions to achieve more effective communication in command centre teams. This design will also be *evaluated.* With this and other research efforts, we attempt to develop a new concept for future Command & Control that improves team effectiveness in the command centre.

	Modelling	**Observation**	**Experimentation**	**Design**	**Evaluation**
Project	Multipurpose frigate	Multipurpose frigate	Intra team feedback	Air Command & Defence frigate	Air Command & Defence frigate SmartStaff
Question	What is the information flow in the command centre?	How can the performance of the command centre be optimised?	What is the effect of intra team feedback on developing shared mental models?	What is the best layout of the command centre to support effective human-human interaction?	Does the design fulfil its' expected effectiveness?
Techniques	- document analyses - visualisation - interviewing - standardisation	- quality indicator sheet - workload registration tool - task performance questionnaire	Low fidelity simulator: *fire-fighting task*	- link analysis - drawings - scenarios - physical mock-ups	- hardware and software mock-ups - questionnaires - scenarios - external assessor - experienced group discussion
Result	clear description of the command centre with 400 interrelated graphical representations	individual task responsibilities dominate teamwork responsibilities	teams perform better when they have the opportunity to engage in intra team feedback	complete workplace layout supporting team effectiveness	- workplace layout mock-up - SmartStaff concept supporting collaborative decision-making and planning

Table 1: overview of the methods, projects, questions, techniques and results

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SmartStaff: a support concept for staff planning

Wilfried Maria Post & Pieter Hamaker
TNO Human Factors
P.O. Box 23
3769 ZG Soesterberg
The Netherlands
Tel. +31 346 35 63 12
Fax. +31 346 35 39 77
Post@tm.tno.nl

SUMMARY

A new concept has been evaluated to support decision making in teams. The concept encompasses a shared representation and interactive use of planning information in a team environment, and consists of individual workplaces, generation and representation of ideas, and shared interactive large screen displays. This so-called SmartStaff concept has been evaluated during a simulated operation by the Task Group Staff of the Royal Netherlands Navy. By means of questionnaires the staff members were asked to assess their current work environment and the potentials of SmartStaff. The results show that the concept provides better general support for group decision making. SmartStaff supported better the presentation and conveyance of ideas, facilitated time management and decreased the ambiguities of the plans presented. However, the quality of the final plan did not improve.

KEYWORDS

Team decision making, Team Planning, Group Support Systems, Task Group Staff

1 INTRODUCTION

A concept for supporting a planning task in a team has been evaluated. The goal of this so-called SmartStaff concept is to support a team in developing a common representation of both the problem space (an operational situation) and the solution space (a plan to be developed). This concept has been implemented in an environment where planners can work both individually and together, while using and producing information in a highly interactive way.

A number of researchers employ the term 'shared mental model' in explaining effective team behaviour (e.g., Orasanu, 1990, Rouse, Cannon-Bowers & Salas, 1992, Stout, 1995). The SmartStaff concept encompasses a *representation* of a shared mental model of the *operational situation*. SmartStaff also includes a *representation* of a shared mental model of *the plan* that the team is developing.

To improve our understanding of team support, our aim is not to evaluate a particular environment but rather the concept behind it. In order to evaluate the concept empirically, we have implemented the concept in a naval command and control task of the Task Group Staff of the Royal Netherlands Navy (RNLN) that has operational command over a number of naval platforms.

Supporting naval command and control teams has been the subject of a large research program called TADMUS (Tactical Decision Making Under Stress); see Cannon-Bowers and Salas (1998) for an overview. Morisson, Kelly, Moore and Hutchins (1998) discuss a number of decision support systems developed in this program,. The design of these systems were based on the naturalistic decision making theory (Zsambok and Klein, 1997), stating that a decision is most of the time based on a recognition of a previously experienced pattern. Decision support should therefore facilitate the recognition of these patterns. Example decision support systems designed by Morisson et al. are a geo-plot (a computer graphic representation of a geographic area with associated information, i.e. land masses, political boundaries, symbols for assets and units), and a track profile (graphically displaying the altitude of an air contact over time and range from own ship). However, supporting team planning has not been part of the research program.

A new conceptual approach is an important aspect of the development of a new command frigate, the platform that embarks the Task Group Staff. Traditionally, the RNLN designs its own frigates. Since the start of operation of the current command frigate, three decades ago, much has changed in the field of information and communication technology. New ways of working have to be designed, updated not only to the current state of technology but also to be prepared for developments in the future. Therefore, a conceptual evaluation is more valuable than merely a state-of-the-art based technological evaluation.

1.1 Technological Development

A most significant change in the past decades is the use of electronic information in groups. McGrath and Hollingshead (1994) give three reasons why teams should work with electronic information:

- it can improve task performance,
- it can overcome time and space constraints, and
- it enhances information retrieval and exchange.

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Important recent developments in command and control are the paperless ship, the large screen displays, and various electronic support tools. Electronic support tools can be categorised in different ways. Group support systems can be distinguished on the basis of time and space constraints (DeSanctis and Gallupe, 1987, Grudin,1997). People can work together at the same place or at different locations, and also work together synchronously or a-synchronously. A second distinction of group support systems is type of task. Computer supported cooperative work can be divided in:

- communication between co-workers;
- creating and maintaining a shared information space; and
- coordination of the various interactions between the co-workers, and between a worker and the information system.

Group systems that support communication mainly deal with groups that are distributed in space, some of which work synchronously (telephone, video conferencing), and others a-synchronously (e.g., e-mail). Desktop conferencing is an example, given by Grudin (1997), of a type of support system that creates and maintains a shared information environment in which group members can share large screen displays and different electronic tools. There are several group decision support system, for example computer conferencing tools, application sharing systems, collaborative virtual environments, audio conferencing systems, and collaborative software engineering systems (Grudin, 1997, Ter Hofte, 1998).

A rather new device that can support group work is the shared electronic whiteboard. Originally, shared whiteboards were used for groups working at different locations who need to work on a common object (e.g., a document) during video conferencing, but it has been found to be useful in face-to-face meetings too. Streitz, Geissler, Haake & Hol (1994), for example, compared three conferencing configurations. In one configuration, a group of graphical designers were provided with individual workstations. In a second configuration, an interactive whiteboard was provided. The third configuration consisted of the mixture of both. They found that designers supported by both individual workstations and an interactive whiteboard performed best, in terms of quantity and quality of ideas, amount of activity, and a shared picture of the subjects of discussion. The whiteboard that was used presented a computer screen and enabled direct interaction or interaction from behind the individual workstations. The whiteboard also allows drawing pictures with an electronic pen. It appears that this concept improves performance, because the whiteboard focuses attention on the design object as well as the design process, and facilitates the comparisons of ideas (plans); while idea generation takes place interactively at the whiteboard, other members can respond to it immediately.

1.2 Support Concept

Planning may be defined as designing a sequence of actions to be taken in order to react upon an anticipated threat with regard to a mission, where all actions are heavily interdependent and where design decisions need confirmed arguments. Team planning requires that information needed for planning as well as the plan itself is shared and that, for efficiency reasons, team members can work both collectively and individually. It is essential that the separate, diverging work of members having individual expertise is followed by convergence of ideas in the team.

Current electronic tools do not support team planning. With an electronic conference tool, for instance, a group can first generate a list of individual ideas and next come to an agreement of the best one. For staff planning, however, a tool is needed that enables staff members to develop a single plan or ideas for plan refinement in a collective and integrated way rather than enabling only individual disconnected idea generation. Further, we think that for interactive planning, it is not only important to share planning information and the plan itself; sharing information about the planning process is essential as well. Information about the planning process gives other members the possibility of reacting immediately during planning. They may contribute concurrently instead of sequentially (i.e., first developing a partial plan individually, and then discussing it within the team.)

On the basis of these ideas the SmartStaff was conceptualized, having the following characteristics. A planning staff needs:

1. Both individual and shared workspaces
2. Flow of information
3. A common focus of attention
4. Concurrent idea generation

An "idea" is used as the unit for information conveyance. An idea can take various forms: text, an object (graphical, but potentially also audio), or even a reference link to another idea. Ideas can consists of sub-ideas. A plan is typically a compound idea.

We have implemented this concept with eight individual workstations and two large interactive touch screen displays (electronic whiteboards), electronic storage, retrieval and exchange of information, and an electronic idea pad: a tool for both individual and team generation and representation of ideas. To guarantee face-to-face contact and an unlimited view of the large screen displays, the workstations were lowered and positioned in a semi-circle around the large screen displays. Figure 1 shows the layout of the experimental staff room.

As idea pad we used a commercially available software tool (SmartNotebook, from Smart Technologies Inc.), but in a specific way. In the idea pad, ideas may be put on a single page, or divided over different pages. The development of an idea may be recorded, enabling skipping back to an earlier development phase. Elements of an idea can be made from scratch or may be imported from existing sources, including other idea pads or idea pad pages. Other available electronic information sources are the tactical situation, meteorological information, charts, mission statement, messages, intelligence, etc.

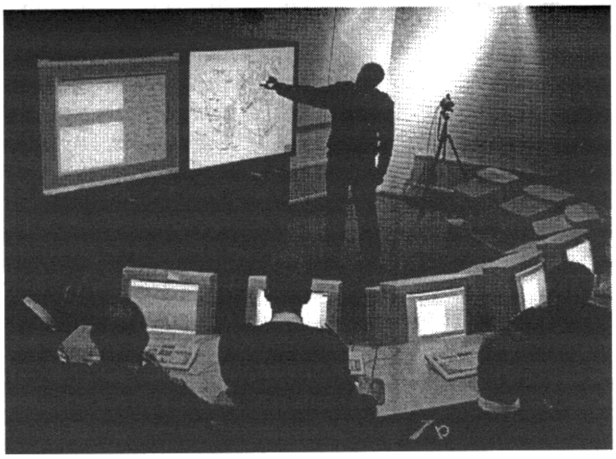

Figure 1: The layout of the experimental staff room.

Ideas can be exchanged with a specially developed tool. When a team member wants to submit an idea he can send his idea pad to a common idea repository, presented at the large screen display with the name of the sender, and a one-line description. The content of the private idea pad can be discussed within the team, and accepted (possibly after revision by the individual or the team) as (part of) a shared team idea, or thrown away. The other way around, a shared team idea can be fetched from the common idea repository and placed on the individual's own work space, for example for extension, correction, or refinement.

1.3 Task Analysis

This paper describes the empirical evaluation of the SmartStaff concept in the naval command and control task of task group staff planning. The aim of this study is to examine whether the team decision making performance improves when the team is supported by the SmartStaff concept. More specifically, we want to investigate whether Smartstaff improves a shared picture of the situation and the plan, is more time-efficient, improves the communication of ideas and the quality of the final plan.

Before the evaluation we first analysed the work of the Staff. Naval platforms seldom operate individually, but rather in a group, called a Task Group. The Task Group Commander, supported by a team varying from five to fifteen members with a specific individual expertise, such as in meteorology, intelligence, communications, and the different warfare areas, exercises command from a dedicated frigate. Monitoring, threat assessment, and control of operations of the whole Task Group takes place in the staff room of this command frigate. Various phases of an operational situation can be distinguished, differing in threat, workload and intensity of the team decision making process. The planning process is illustrated in figure 2.

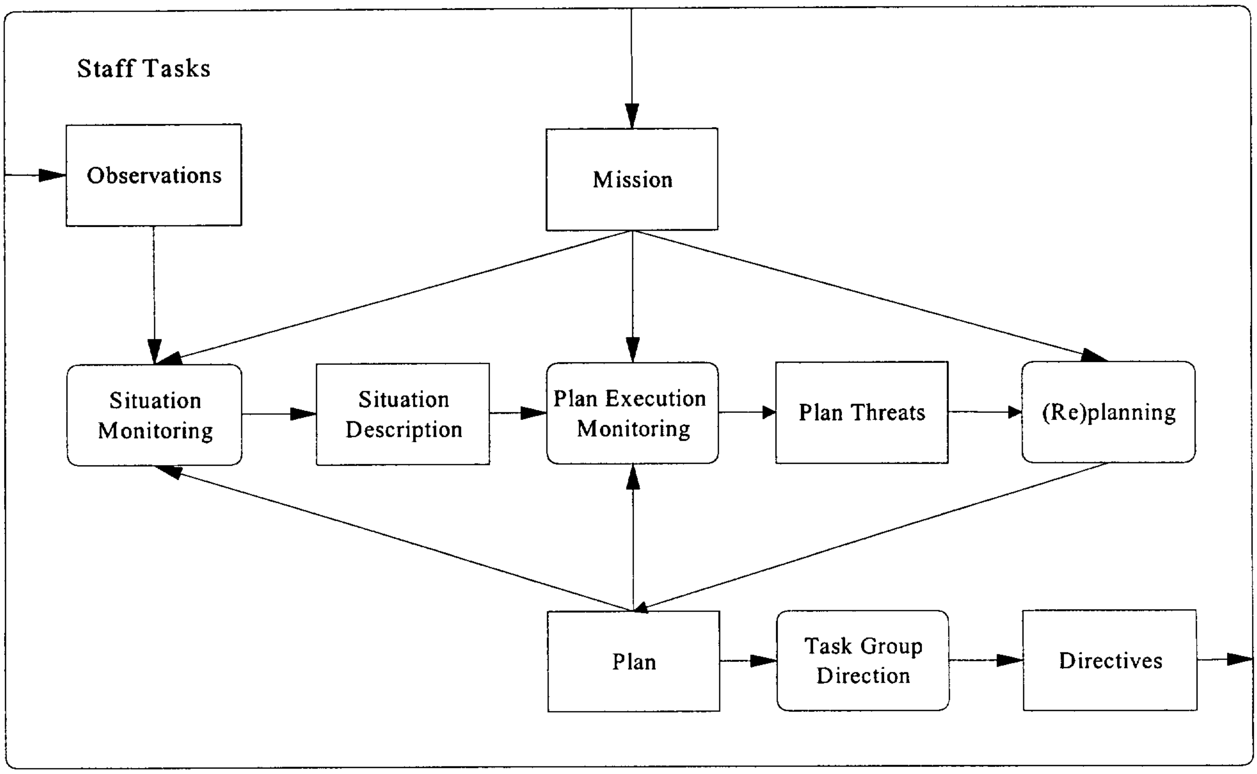

Figure 2: Staf tasks. The rounded boxes are tasks; the shaded boxes are information boxes; arrows are data dependencies

Based on its mission, the Staff plans the activities of the task group and executes the plan by directing the units. During execution, both the situation and the execution progress is monitored. When the situation changes and problems in executing the plan are anticipated, or the mission changes, the plan is revised. This process is carried out in three cycles:

1. long-term (re)planning (more than half a day in advance)
2. short-term (re)planning (up to half a day in advance)
3. near-real-time decision making

During these cycles, briefings take place regularly to inform the members of the staff. Re-planning occurs by generating collectively a solution in a rough form, and then working out the details in the plan individually, and next, discussing them collectively. The final adaptations are translated into orders and sent to the task group units.

In its current environment, the Task Group Staff does not work much with electronic information. The Staff does not have electronic presentation or electronic data exchange facilities; much is done on paper, and on white boards and tote boards.

2 METHOD

2.1 Subjects

All 14 RNLN Task Group Staff members served as subjects, 6 Petty Officers 1st class, 6 1st Lieutenants, a Captain and a Commodore. The 1st Lieutenants were experts in one or more particular areas (operations, the three warfare areas, meteorology, communication, and intelligence). The Captain and the Commodore were the team leaders. The Petty Officers supported the Officers. All subjects had significant operational experience, also within this team (except for the Captain). Mean age was 39 years (34 to 50).

2.2 Design

The RNLN Task Group Staff carried out their work during a simulated operation in the SmartStaff-based environment. For pragmatic reasons, we were not able to make a pure experimental comparison between this environment and an environment not based on SmartStaff . Only one RNLN Task Group Staff exists and its time is restricted. Therefore, the staff members were asked to compare this experimental environment with their normal working environment. To make their work as similar as possible, we used an operational scenario that was comparable with a training scenario they had used earlier in their current environment. In addition to this self assessment, we invited two experts in the field as independent observers, to collect information for the interpretations of the results.

Three questionnaires were developed: one for assessing the current environment (A), one for assessing SmartStaff (B), and one for comparing directly both environments (C). With the three questionnaires, SmartStaff was tested in two ways:

- Indirectly, by comparing the questions about the current environment (questionnaire A) with the questions about SmartStaff (questionnaire B)
- Directly, by testing the null hypothesis that SmartStaff and the current environment supports the Task Group Staff equally well. This is done by comparing the questions in which both environments were compared (questionnaire C) with the answer 'equal'.

The subjects as well as the observers filled out the three questionnaires. The questions in each questionnaire were organised in 5 modules:

1. point of focus and shared picture (3 questions), e.g., "How often during a meeting in <the current environment> do you have a different picture of the situation than a colleague?"
2. efficient use of individual and shared time (5 questions), e.g., "How often during <the SmartStaff meeting> do you experience that you lose time?"
3. communication of ideas (5 questions), e.g., "Can you clarify your ideas with SmartStaff better than in the current environment?.
4. product quality (1 question), e.g., "How do you assess the mean quality of the plans resulting from the <current environment>"?
5. general questions (12 questions) , e.g., "How well can you present your ideas to the team in <the current environment>?"; "How well does <SmartStaff> support you in participating in the team discussion?".

In questionnaire A and B, answers had to be given on a 4-point scale (bad, rather bad, rather good, good). In questionnaire C, a 5-point Likert scale was used (with answer categories 'much worse', 'worse', 'equal', 'better', 'much better'). This questionnaire also asked some open question about both environments, such as about their strengths and weaknesses, possible improvements, and the potential of SmartStaff, e.g., "Do you have any suggestion for improving SmartStaff?"

The subjects as well as the observers also took part in a group discussion, taking place after having experienced the SmartStaff environment. The group discussion was also based on qualitative questions.

2.3 Scenarios

A realistic simulation in the environment described above requires a full scenario in which the Staff directs a Task Group consisting of various frigates, tankers, an amphibious unit, air units, and a submarine, within political constraints laid down in so called Rules of Engagement. The scenario was based on a training scenario, adapted to the above mentioned three team decision making cycles.

For long-term planning, the task was to prepare a plan to escort a Task Unit to a particular waiting area prior to an amphibious landing by NATO forces, and to execute the plan within 76 hours. For short-term planning the task was to formulate a group assessment of the present tactical situation, including a tentative identification of surface contacts, and to (re)task available assets and units in order to accomplish the task. For near-real-time decision making, the Staff had to assess the development of the tactical situation, to reconsider eventually the identity of the surface contacts, and to decide on manoeuvring the formation or to engage. Information needed for planning and decision making, such as mission, rules of engagement, observations, meteorology, intelligence, possible threats, etc., was made available electronically.

2.4 Procedure

One week in advance, the information used in the scenario, consisting of 30 pages of text, sea charts, etc., was provided to the Task Group Staff. Data collection took place in one afternoon, from 12 to 6 pm. After a short explanation of the aim of the study, the subjects filled out questionnaire A. After lunch, the SmartStaff concept was introduced and explained. Next, the subject were trained for one hour in using the support tools, working through a number of exercises about forming and presenting ideas, and sending and fetching them. The game started at 2.30 and lasted for two hours. In the first hour of the game, long-term planning took place, without the Task Group Commander (TGC). The plan was subsequently briefed to the TGC. In the remaining time, short-term planning and near-real-time decision making was carried out, as a reaction to a developing threat. In these tasks, the TGC participated fully. After a break, questionnaires B and C were filled in. The session concluded with the group discussion.

2.5 Results

The results came from the three questionnaires filled in by eight staff officers, the questionnaire filled in by one observer (the second observer didn't show up), and remarks made during the group discussion. Reliability analysis showed that two items in module 2 (efficient use of individual and shared time) had low item-total correlation; these items were left out of the analysis. The reliability of the remaining questionnaires was reasonable to good (Crombach's alpha .97 for questionnaire A; .74 for B; and .71 for C).

In table 1 the results are presented for the four specific performance criteria, derived from the first four modules from the questionnaires. A fifth overall performance assessment is added, derived from all five modules. A Wilcoxon rank test was used. Each performance criterion was tested by averaging the scores across the questions of a module. The table shows the mean scores together with their standard deviation (between brackets), and the level of significance (p-values).

The Task Group Staff assessed that the SmartStaff based environment supported their decision making better than their current environment ($p \leq 0.05$ for both comparisons). Important to remark is that the subjects regularly noted they evaluated in questionnaires B and C the potential of the SmartStaff *concept*, not the current experimental *implementation*, for which is clear that certain interaction mechanisms and the speed of data exchange can be improved.

SmartStaff was found to provide a less ambiguous shared picture shared of the situation and the plan, when the two environment were compared directly ($p < 0.05$). No significant difference was found for the absolute assessments of the two environments.

The Staff also had the opinion that with SmartStaff their time was used more efficiently. Again, this result was only found in the direct comparison ($p < 0.5$). A drawback, put forward by some subjects, was that carrying out individual work in the SmartStaff environment may distract one from shared decision making.

Performance criterion	Mean Score (Standard deviation)			p-values of difference	
	A	B	C	A-B	C-'equal'
	Cr.α=.79	Cr.α=.74	Cr.α=.71		
overall performance (module 1 to 5; 24 questions)	2.81 (0.32)	3.01 (0.30)	3.77 (0.25)	.05	.01
shared situation picture (module 1; 3 questions)	2.95 (0.49)	3.29 (0.42)	3.49 (0.32)	n.s.	.02
time efficiency (module 2; 3 questions)	2.96 (0.49)	2.92 (0.43)	3.65 (0.49)	n.s.	.02
idea communication (module 3; 5 question)	2.66 (0.32)	3.08 (0.55)	4.22 (0.41)	.06	.01
product quality (module 4; 1 question)	3.25 (0.46)	3.13 (0.35)	3.33 (0.41)	n.s.	n.s.

Cr.α: Crombach's alpha; n.s.: not significant;
A: Current environment; values ranging from 1-4 (bad, rather bad, rather good, good);
B: SmartStaff environment; values ranging from 1-4 (bad, rather bad, rather good, good);
C: Direct comparison; values ranging from 1-5 (much worse, worse, equal, better, much better).

Table 1: Overview of the results

With SmartStaff, the quality of ideas generated is not better compared to their current environment (p= 0.35 for comparison afterwards, and p=0.11 for direct comparison).
The Task Group Staff was clear about the value of SmartStaff for the communication of ideas. The subjects unanimously thought that the SmartStaff based environment is better or much better in this respect compared to the current environment. (p=0.06 when indirectly compared; 0.01 for direct comparison). Also, in their comments the subjects expressed the strength of SmartStaff on this aspect.
The assessment of the observer was in accordance with the assessment of the Task Group Staff.

4 GENERAL DISCUSSION AND CONCLUSIONS

4.1 The results

The results have shown, that the SmartStaff concept has a large potential to support the planning in teams. In several respects, a SmartStaff based environment provides better support for team decision making than traditional environments:

- the shared picture of the situation and plan that staff members have is better and less ambiguous,
- time is managed more efficiently,
- presenting and communicating ideas and plans runs much better,
- general support to team decision making is better.

In one respect, SmartStaff did not have any effect: the quality of the ideas and plans were not influenced.

The latter result seems to be in contrast with the findings of Streitz and colleagues (Streitz, Geissler, Haake and Hol, 1994, Streitz, Rexroth, P. and Holmer, 1997). They found an improved output in terms of both quality and quantity when a group designed a logo together while supported by individual workstations and shared interactive large screen displays. In that task, however, the members of the team all had the same expertise and did not work together on a single logo; they generated a number of them and then selected the best one. So, the type of task and the homogeneity of the staff and the logo designers are different and a comparison can not be made easily.

It would be interesting to find out why the quality of the final plan did not improve. One explanation may be that in a planning task, in contrast to real-time decision making, sufficient time is available to make the plan better. A difference in output would only be found when there are time constraints. In such a situation, more efficient time management will play a critical role.

Individual comments of the subjects and remarks during the group discussion pointed out a number of additional aspects. The advantage of interactive large screen displays to support idea presentation and communication was particularly clear for long-term planning and for briefing. A better and less ambiguous shared picture was also found for short-term planning and near-real-time decision making. Another positively assessed aspect was the possibility of reviewing the course of the decision making process. Time management was found to be more efficient: the subjects found it easy to change from individual tasks to collective tasks. It was recognised, however, that individual tasks that demand much concentration, could better be carried out in isolation.

4.2 Limitations of the method

Firm conclusions are limited by the method used.
One methodological problem may be the Hawthorne effect: is the effect not just a result of running an innovative system? This may be avoided by asking the staff to work in new environment for some time and measure again. Unfortunately, this is practically unfeasible. The results show, however, that the subjects were not positive on one particular aspect: quality and quantity of the ideas did not improve. Also, during the group discussion, it became clear that there was at least some reluctance to accept the new technology. These two observations may indicate that the subjects may not have been influenced by the Hawthorne effect.
Using a real team instead of artificial teams has the advantage of ecological validity. We have studied a team in its real working environment, with members having specific individual knowledge, experience, and skills who are used to working with each other. A drawback is the practical consequences. It is difficult to carry out tests on a Task Group Staff since there is only one such team in the RNLN. Still, the impact of their decision making process is enormous, so research is important, even within these methodological constraints.

4.3 Conclusions

Our aim was not to fine tuning a particular implementation but to carry out a conceptual evaluation in an early phase in a systems engineering life cycle. Such an evaluation yields the functional requirements of a system (see e.g. Sage, 1992). Neerincx, Van Doorne and Ruijsendaal (1999) show also that support systems can indeed be evaluated in an early phase. They distinguish a task level and a communication level evaluation, the former can be carried out far before the system is operational. The lessons of a conceptual evaluation are independent of the state of technology, and therefore last longer. Moreover, it helps us to understand how teams work and how they should be supported.
The present findings raise a lot of questions. Further work will address why the final product of the staff did not apparently improve. We would like to know whether this depends on group characteristics (a heterogeneous team used to work together) or type of task (no time contstraints). A second question, following from the first one, is whether other types of teams may profit from SmartStaff also. Does a management board experience the same level of support? A third question is how team planning and refinement is carried out at a cognitive

level. For complex tasks, a human being has a number of mechanisms available for problem solving simplification, such as satisficing (Simon, 1978). Satisficing is a problem solving strategy often used by designers: they are satisfied with a solution to their problem when it satisfies the constraints, without further searching for a better solution. It may be the case that the product of planning and refinement can only improve when the planning problem or the problem solving strategy is more complex. If so, team planning needs specific cognitive support to manage the complexity.

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Command Decision-making aided by Dynamic Sociography

Ph.D. Col(ret) Jaroslav Sykora,
M.D., LTC(ret) Joseph Dworak, Ing,
Pavel Michalek, David Novotny
Center of Social Studies, Ministry of Defense
Stress Research Center
High Military College of Ground Forces, Czech Army
Mladoboleslavska, Kbely Airport
Prague 9, Kbely, 197 06, Czech Republic

Phone: +420-02-20 207 444
Fax: +420-02-850 15 32
E-mail: sykoraj@army.cz

Introduction:
Command and control operations became increasingly more complex if not chaotic under real battle conditions. At the same time the importance of psychosocial factors in battle management operations increases. Thus the uncertainty of decision making is enhanced. The aim of our research is to augment the cognitive utility in command and control management processes, using new information technologies of dynamic sociometry for the analysis of systems, based on uncertain, ambiguous, and poorly defined elements.

Rationale:
Under NO PEACE, NO WAR conditions of contemporary conflicts, targeting is a substantial part of the process of decision making. Decision about targets for action has been performed nearly exclusively by intuition. This is still more valid in decisions including the aspects of psychosocial operations. Suitable objective methods of the analysis of target aiming are lacking.

Description of methods employed:
Bahbouh in our laboratory developed a complex method of dynamic sociometry (or -- graphy) based on fuzzy logic and graph theory. The method is a qualitative development of the classical Moreno's sociometry. In general, it can be used to the analysis of any system. We use it to analyses of social complexes (micro- to macrogroups) by evaluation of intra- or intergroup relations. The result is an objective description of subjective interpretation of relations within a complex system.

It is possible, using fuzzy sets, to compute degrees of appurtenance of qualitative data, and to express in this way the relations of elements (subjects, individuals, and groups) in a complex system. The final outcome of the analysis is presented in form of a map, where the distances represent social relations (near – positive, sympathetic, or distant – negative, aversive) and altitudes correspond to high or low social positions of elements in a system. The highest position usually in the center of the group is that of the "STAR", the lowest, on its periphery, are those of "OUTSIDERS". An important position is that of the "BRIDGE". This is a subject with a rather mediocre position, but with prevailing positive relations. A bridge subject can play an important social role as a mediator among different elements of the complex, suitable to arrange coalitions and cooperation. To be more users friendly, the map is completed by isohypses. The configuration of the "social terrain" corresponds to the relations under analysis, the "slopes" or "valleys" representing obstacles, difficulties in mutual understanding and/or sentiments.

The reliability and validity of the method were tested under real conditions of the activities of our Center as the expert laboratory of the Chief of General Staff of the Czech Army.

Results obtained:
Reliability and validity of the method were tested with success in a group of three subjects during an experimental simulated space orbital mission (changes during 153 days of social deprivation).

The method was verified on a complex group of groups in the whole Czech Air Force.

Preliminary results of these two mentioned real situations were referred elsewhere.

This year we analyzed relations during the Kosovo conflict on the level of macrosocial processes by the aid of a dynamic sociometric model.

Expeditionary units of Army of Czech Republic operate in the Bosnia and Kosovo regions as a part of the NATO forces. Taking the post-hostilities period problems into account, the knowledge about psychosocial conditions, local or regional, is much needed. At the same time it is important to lay down interpretation of a possible future development of the strategic situation in its broadest aspects.

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Social relations of all macro-groups participating in the conflict were evaluated using heuristic approach and formed into a sociometric matrix. On its base the sociomap of their relations was constructed (Fig. 1). As seen from the map, NATO, Russians and Milosevic assume the most important social positions.

The prognostic value of dynamic sociometry becomes apparent if used as a model (Fig. 2). When the influences of NATO, Russians and Milosevic were eliminated under simulated conditions, the whole social complex of the Kosovo conflict participants, representing a relatively homogenous situation as yet, disintegrated into three separate groups: two extremes (the Serb grouping and the Albanian one) and one central (Montenegrins).

Relatively deep "valleys", separating the inimical parties, witness deep discrepancies. Without doubt, if the external pressures of NATO, Russians and Milosevic would be absent, an immediate blowing up of hostilities and violence would result.

An important problem is the verification of similar social models. This can be accomplished in two ways:

(1) Taking intuitively into account some logic of events.

(2) In comparison with real evolution. In this relation I should like to emphasize that this prognosis was accomplished on Oct. 31st 1999.

Conclusions:

Dynamic sociometry makes a deep analysis of internal and external relations of any system possible, pointing towards weak spots in system's relations, asking in social systems for the leading "Star" or neglected "Outsider" within the system, respective for the "Bridge" only. It is applicable to any intricate, uncertain and ambiguous complex system whatsoever.

Understanding human relations using sociomapping proved in practice as a potent prognostic aid. We emphasize that the use of dynamic sociometry is not limited to psychosocial events only. The sociomap is a reliable and valid model of complex situations. It is possible to demonstrate the expected future course of events resulting from command decision making under extremal, poorly defined and uncertain situations.

Legend Figure 1 and 2

FIG. 1: Sociomap of the situation in Kosovo, October 1999

Legend:

NATO – NATO forces
RUS – Russian Units
Mil – Milosevic Party

Alb – Albanian Republic
Rug – Rugovoi Party
UCK – Kosovo Liberation Army
Bos - Boshniaks

MD – Montenegro Democrats
MAC – Macedonian Republic
SD – Serb Democratic PArties

MAD – Montenegro Antidemocratic Parties
SAD – Serb Antidemocratic Parties
SARM – Serbian Army

FIG. 2.: Simulated situation in Kosovo October 1999,
after exclusion of Milosevic, Russia and NATO forces.

Fig. 1: Sociomap of the situation in Kosovo, October 1999 (see legend)

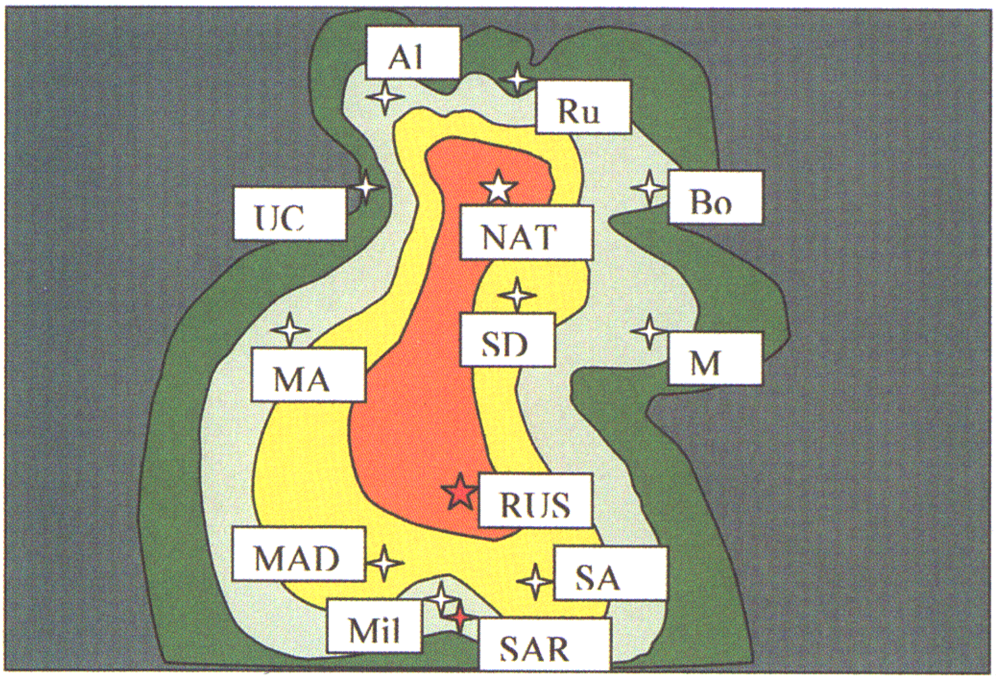
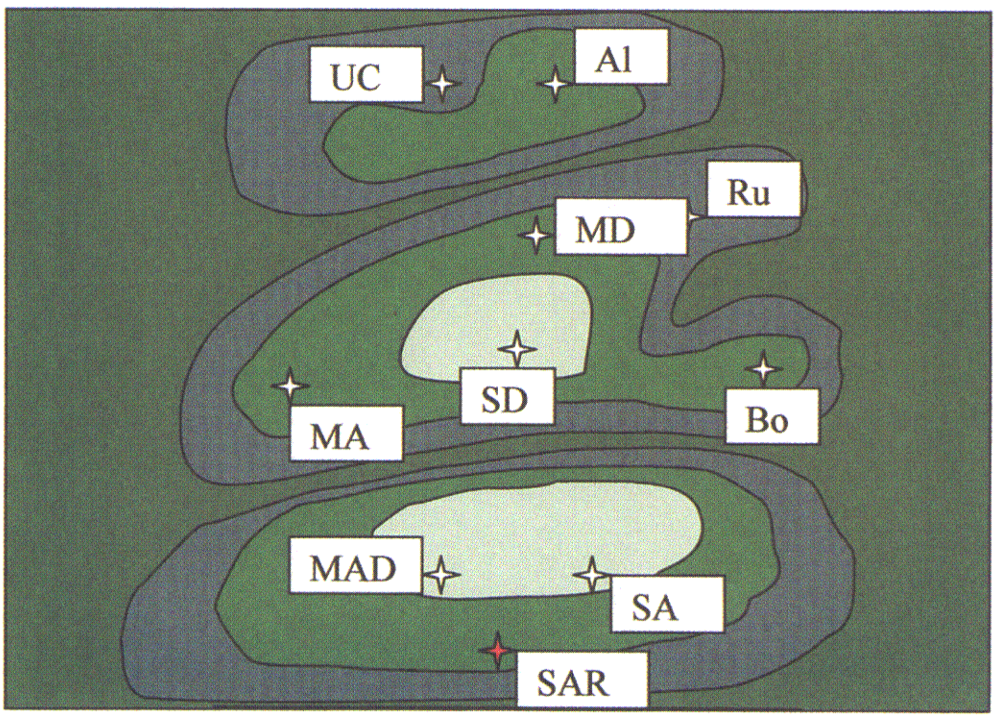


Fig. 2: Simulated situation in Kosovo October 1999,
after exclusion of Milosevic, Russia and NATO forces.



Toward a Methodology for Evaluating the Impact of Situation Awareness on Unit Effectiveness of Dismounted Infantrymen

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Cynthia L. Blackwell
USA SBCCOM-NSC
ATTN: AMSSB-RSC-MA(N)
Natick, MA 01760
USA
and
Elizabeth S. Redden
U.S. Army Research Laboratory
ATTN: AMSRL-HR-MW
Ft. Benning, GA 31905-5400
USA

Introduction

The United States (US) Department of Defense initiated a program in 1997 called the Military Operations in Urban Terrain Advanced Concept Technology Demonstration (MOUT ACTD). MOUT ACTD is a joint US Army-Marine Corps. program led by the US Army Soldier and Biological Chemical Command. The MOUT ACTD's charter is to seek technologies that satisfy 32 jointly derived requirements specific to operations in 'built up' or urban areas. MOUT ACTD evaluates these candidate technologies for military utility and transitions the successful candidates to acquisition programs for further development and fielding.

One of the determinants of military utility that the MOUT ACTD program uses is situation awareness (SA) - specifically, the influence of SA on individual and force effectiveness as a result of the use of MOUT-related technologies. SA is defined here as the warrior's ability to quickly perceive and then discriminate between facets of the tactical environment, to accurately assess and reassess the where, when and why of that environment, to then know and understand the nature of the tactical situation and to extrapolate near term courses of action based on this understanding. This paper describes the process by which the MOUT ACTD program developed and implemented a method for determining the impact of SA on individual and force effectiveness.

Background

Behavioral scientists have investigated SA to a great degree in U.S. Navy, Air Force, and Army aviation communities. SA, as it relates to dismounted infantry operations, is an emerging area of study. The excellent research in this field conducted by the aviation community, in both individual and crew SA, has made it possible for behavioral scientists to formulate new approaches of investigation of SA for the dismounted war fighter and small infantry unit.

With the advent of advanced technologies and battlefield digitization, materiel developers are now required to provide connectivity between the dismounted infantryman (DI) and the digitized battlefield through novel communications, sensing and command, and control-enhancing technologies. For example, many U.S. soldiers may soon be provided wearable computers to aid individual and small unit command and control operations. The technologies incorporated in these computers include advanced sensors, communications, and navigation. These technologies have the potential to directly impact, both positively and negatively, the ability of the war fighter to perceive his or her environment and to understand his or her place in it. The war fighter must be able to interface with these technologies to best employ the capabilities they provide. Research needs to be done to first understand the impact these capabilities have on the warfighter's cognitive abilities and ultimately to interweave the output of these capability-enhancing technologies into the infantryman's decision-making processes that ultimately impact battlefield outcomes.

SA Measures of Effectiveness and Performance

There is a variety of factors that indicate how effectively a war fighter operates in a battlefield environment. How individual and small units employ new technologies is a function of this effectiveness. The operational effectiveness factors include casualty ratios, logistics resupply, combat support, lethality, and survivability. Another of these factors is SA.

Mission accomplishment is the critical operational factor in determining the relative military utility of a piece of technology. The basic premise of the MOUT ACTD SA effort is that the more situationally aware a force is, the more lethal, mobile, and survivable a force is.

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Quantifying this was and is the ultimate goal of the MOUT ACTD SA effort.

In order to reach the goal of developing a methodology for quantifying the influence of SA on performance, it was necessary to find a way to determine its value in a field environment. The challenge was to define objective, field expedient, operationally based measures for determining the influence SA has on mission performance. To accomplish this, a panel of experts was convened at the US Army Research Institute, Ft. Benning Georgia, USA. The charter of this panel was to determine measures for SA that would quantify changes in combat effectiveness. The panel was composed of active duty and retired Army and Marine Corp. officers and enlisted personnel, training experts and behavioral scientists. The panel met on four separate occasions corresponding to scheduled experiments during which particular SA-impacting technologies would be used.

Goal-Directed Knowledge Elicitation Technique

A formal process was needed to solicit the required field-expedient measures. The panel used what came to be called the Goal-Directed Knowledge Elicitation Technique (GDKET) to accomplish this. This technique was developed as a way to solicit situation-specific mission needs from subject matter experts (SMEs). These mission needs were established to provide the means by which specific mission goals were reached and the knowledge of what must occur on the battlefield in order to reach those goals, which served as the foundation of the SA measures.

GDKET was developed based on the goal-directed task analysis described by Endsley in "Situation Awareness Information Requirements for En Route Air Traffic Control" (Endsley & Rogers, 1994). The general approach described by Endsley and Rogers is the same used here; however, the specifics of expert knowledge elicitation and requirements analysis differs in that GDKET uses a panel of experts to identify mission goals. GDKET also relies on the interplay of the experts during role-playing to generate requirements that form the basis of the SA measures of performance. The behavioral scientist serves as an observer and facilitator to cull the requirements from the panel's discussions in a non-invasive way. In GDKET, the experts assist in analyzing the requirements and devising the measures. Emphasis is placed on obtaining field expedient measures, and the GDKET approach allows these to be obtained.

In the GDKET mission vignettes were developed that incorporated individual and small unit tasks during which MOUT ACTD technologies could be employed. An example of one such mission vignette was clearing a building of enemy troops. The panel discussed the mission vignette in order to achieve a common understanding of the mission. Experts, in turn, were queried about their role in the mission (e.g., platoon leader, company commander, squad leader). After this had been established the vignette was "role-played," thereby soliciting the dynamic elements of the mission including tactics, techniques and procedures (TTPs) and standard operating procedures (SOP). All this was done independently of technologies employed during the mission.

The panel members were queried about their tasks as well as their intent at different levels of granularity with respect to the mission. For example, in the building clearing vignette, the squad leader was asked to describe his activities during the mission. He described his mission goal first (clear a floor in the building of enemy soldiers) then general mission tasks (e.g., providing status reports to his platoon leader). Based on the mission goal, sub-goals and supporting tasks were identified. An example of a sub-goal was to ensure that the squad has adequate supplies of ammunition and water during the mission. Supporting tasks included periodic querying of fire-team leaders about their ammunition status and passing that information to the platoon leader.

A list of operational requirements was generated and these formed the basis of the SA measures. The following is an example of some of the information requirements generated for a squad leader during a building clearing mission and the resulting measures:

Squad Leader must know:

- Location of platoon leader
- Location of other squads
- Ammunition, water and equipment status
- What rooms and floors have been cleared – how many are left
- Status of fire teams
- Room and floor layouts - blueprints
- Location of the enemy – what floor
- Location of non-combatants and animals
- Casualties
- Prisoner of war collection points
- Location of Platoon Sergeant for resupply
- Some of what the platoon leader knows

Measures:

- Measure the information actually reported against the expected information. Based on TTPs and SOPs the assumption is that communications within a unit will be 100% accurate. The reality is that some messages do not get through.
- Frequency of reporting. How often was a report presented and received versus when it was expected, based on TTPs and SOPs.
- Accuracy of report. Was the report received accurately; was it complete and did it contain the correct/intended information. This is a function of quality of information provided to/and presented by the sender

- Timeliness of report. Were the reports sent when required? This is based on TTPs and SOPs.
- Two-way communication. Quality and quantity of interaction.
- Reduced risk of fratricide.
  - -Unit-to-unit proximity
  - -Status and location of friendlies
  - -Number of wounded
- Number of correct decisions made. A function of advancing the mission, momentum - are the correct decisions made at the appropriate time?
- Speed and reliability of report.

The panel realized that some of the measures could be used near term to determine combat effectiveness, but some (e.g. reduced risk of fratricide) would require long-term experimentation to determine the real impact.

At the end of the GDKET exercise, the panel was made aware of the new capabilities that they would have available to them to use during the mission. For each mission vignette, the experts discussed the impact of these capabilities on their goal, sub-goals, and supporting tasks. The objective was to determine if there would be any impact on current TTPs or SOPs as a result of having these capabilities. This review did not generally change the nature of the TTP or derived measures.

SA Metric Development

After development of the general measures of performance and effectiveness using the GDKET, the MOUT ACTD program commissioned the U.S. Army Research Laboratory's Human Research and Engineering Directorate (HRED) Fort Benning Field Element to develop and validate an SA assessment metric for use in a MOUT ACTD field exercise as an objective measure of SA. The purpose of this measure was to evaluate the effect of the MOUT ACTD technology on the unit's SA. A unit equipped with current technology was used as the baseline in this assessment. Before development of the metric, several decisions had to be made. First, the type of assessment techniques to be used had to be selected. Second, the decision had to be made concerning the time of administration of the technique. Third, the type of exercise had to be decided.

Questionnaire Assessment of Knowledge Technique

Endsley (1995b) proposed that the ability to objectively measure SA is critical for progress and understanding in the field. She critiqued several measurement techniques that have been performed in the past to objectively measure SA. These include physiological techniques such as electroencephalographic measurements; performance measures used to infer SA (e.g., time to complete a scenario, loss exchange ratio, etc.); global measures of overall operator performance which give the end result of a long string of cognitive processes; subjective techniques such as self-rating and observer rating; and questionnaires about SA knowledge that evaluate against reality. She suggested that the questionnaire method provides an objective and direct assessment of SA.

Freeze-frame Technique

The questionnaire method can be administered during several different points in an exercise. It can be administered at the end of an exercise, during the conduct of an operator's simulated tasks, or using a freeze-frame technique. Endsley (1995b) found the freeze-frame technique to be more timely than the post test questionnaire and less disruptive than the on-line questionnaire. However, other authors have found fault with the freeze-frame technique. An often-stated criticism of the freeze-frame technique is that it is intrusive since it induces a temporary halt in the scenario (Sarter & Woods, 1991). However, in a simulation using fighter pilots, Endsley (1995b) found that the freeze-frame technique did not affect subjects' performance. She stated that the subjects' SA did not have a chance to decay during the freeze-frame before the SA simulation resumed. In other words, the SA was still intact and the freezing of the scenario did not have an adverse effect on the outcome of the scenario.

Free-play Exercises

Realistic aviation simulators have facilitated the study of SA in the aviation field. Pilots can be placed in the cockpit of simulators that are almost indistinguishable from the real thing. The pilots can then be presented with stimuli that are carefully controlled and processed. The response choices to these stimuli are few and the correct response choice is known when the simulation is developed. However, realistic simulations of the full range of infantry activities that allow assessment of SA have not been developed. The infantry environment is extremely dynamic and interactive, with many possible decision choices. An infantry simulation exercise cannot be limited to a single infantryman, because he operates as part of a unit or team and against other units or teams. Team SA requires a much more complex assessment than does combining the assessment of SA of individual team members. It requires assessment in its own right because it involves unique activities such as coordination and information sharing (Salas, Prince, Baker, & Shrestha, 1995). The decision choices in such an exercise are often numerous and they result in a decision choice matrix that is very complex. Also, outcomes are numerous and cannot be predicted before the exercise. For example, a scenario planner has no way of knowing how often an infantryman may shoot during an exercise and thus does not know ahead of time the correct answer to the SA question "how many rounds of ammunition do you have left?" A further complication of the ability to simulate the infantryman's environment is the fact that the infantryman is "moving, shooting, and communicating" while he attempts to maintain SA. He is not contained in an encapsulated environment such as a cockpit. Because of these factors, the only current way to realistically replicate most of the critical aspects of the environment is in a free-play exercise.

Free-play exercises have been used for many years to train soldiers in combat skills. Units start training using free-play exercises at the squad level. They conduct squad exercises to practice their basic infantry skills (e.g., fire and maneuver, navigation, and weapon skills). Once these skills are perfected, squads come together under a platoon leader to test their individual training against an opposing force in a free-play exercise. The platoons then unite under a company commander to practice. The final evaluation of a commander is the evaluation of his unit during a force-on-force free-play exercise against a well-trained opposing force. The use of free play presents the unit commanders with an almost infinite number of decision possibilities and demonstrates the cause and effect outcome of the decisions.

Metric Development

Once the decisions were made to use questionnaire direct knowledge assessment, freeze-frame timing, and a free-play exercise, the HRED Field Element began work to develop the specific SA metric that would be used during the assessment. Development of the SA metric involved the following essential steps.

First, the developer acquired as much knowledge as possible of all facets of the scenarios planned. This included knowledge of the terrain on which the event took place; knowledge of the operations order that was provided to the unit to include objectives, constraints, and the time of day the operation would take place; and knowledge concerning the enemy opposing force such as the type of weapons they might carry and the number of enemy troops. The scenarios and threat used for the exercise were standard scenarios developed by the Army based upon a typical mission and threat. Scenarios that contain lots of action by either the enemy or the friendly forces are ideal for use in SA assessment.

Once knowledge of the scenario was gained, determination was made of how many freeze-frames were needed and where to place the freeze-frames in the scenario. Infantry SA is not static, but rather the result of ongoing processes within the unit. Therefore, a single measurement point was not adequate. SA assessment should be made over a series of important events while the unit is performing tasks (Salas et al., 1995). In a large exercise, the timing of each freeze-frame is critical. Endsley (1995b) found that subjects in her aviation study were able to provide information about their SA about a specific situation for as long as 6 minutes. Therefore, the freeze-frames were planned to take place no more than 6 minutes after critical situations occurred. Generally, the freeze-frame should provide as little disruption as possible. It was decided that the times just before naturally occurring breaks in a scenario were good locations for placement if these occurred within 6 minutes of critical SA elements.

Next, the developer identified critical SA elements that were contained within the specific event. This knowledge was acquired by holding an SME conference. A group of SMEs that were knowledgeable in the field of infantry and had experienced situations similar to those that would take place in the free-play exercise were best able to determine what the critical SA elements were for the specific exercise. These SMEs proposed SA elements that would be contained in the scenario and then prioritized them in terms of their importance within the scenario. Because it was desired that the amount of time during the freeze-frame would be kept to a minimum, only critical information was assessed. While many SA- critical elements are common across different types of scenarios, some are scenario dependent. Therefore, each set of SA queries was tailored to the specific type of scenario that was used. Not all critical SA questions were naturally occurring parts of a scenario. Sarter and Woods (1991) suggested that complex scenarios should include embedded events to elicit key situation assessment responses. The inclusion of several such events in the scenario allowed multiple opportunities for assessment. For example, an enemy operations order was left behind for the friendly soldiers to find. The transfer of this information to different levels of command was tracked through controlled queries at key points in the scenario.

The developer then determined the level of questions to present. Endsley (1987, 1988, 1995) defined SA as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." Endsley's definition of SA discussed three levels: perception, comprehension, and projection. Perception (Level I SA) is the lowest level of SA because it involves only the conscious knowledge that something is present in the environment. Level 2 SA or comprehension is the synthesis of disjointed perceptions so that understanding of the significance of the perceptions is present. Projection (Level 3) SA is the ability to project future courses of action based upon the understanding gained from Level 2 SA. The critical SA elements identified for the scenario contained all three levels of SA, but the concentration was on Level I because more Level I critical elements naturally occur in a short time period.

Development of the specific SA questions to be administered to the soldiers was the fourth step. While many of these are natural extensions of the critical SA elements that were developed in Step 3, the explicit wording of the questions is critical to the assessment outcome. For example, when asking a platoon leader how many wounded he has, it is important to specify whether you mean in the headquarters' element or in the entire platoon. It is also informative to have the respondent identify the source of his or her information for each SA question. The source question identifies from whom (i.e., platoon leader, squad leader, rifleman, etc.) or what (i.e., visual acquisition, auditory acquisition, over the radio, etc.) the information was gleaned. For example, if the purpose of the SA evaluation is to assess the contribution of a technology to the respondent's SA, then a source question can assist in the determination of whether the technology facilitated an increase in SA or whether it was another factor or another type of technology.

Once all the questions were refined, the next step was the definition of "ground truth." Ground truth is defined as the actual or "true" battlefield situation. It serves as the basis of comparison for what the subject perceives the situation to be. This is the most difficult and one of the most critical aspects of the development of a SA free-play experiment. Without an accurate definition of ground truth, an evaluation of SA cannot be made. In a free-play exercise, ground truth definition can come from a number of sources. If you have an instrumented facility, ground truth can come from position location devices or video cameras. Even if instrumentation is available, it is good to have a backup source of ground truth. Evaluator controllers are SMEs who accompany the unit members (friendly and enemy) during the exercise and are an excellent source of ground truth. Therefore, for each SA question, a matrix was developed to illustrate the source for ground truth. Sometimes more than one source was developed. For example, if the SA question asked a platoon leader how many enemy were on his objective, ground truth was obtained from video cameras on the objective, from position location devices on the enemy troops, and from evaluator controllers co-located with the enemy.

The final step was the SME ground truth questionnaire that was developed after the SA questionnaire via the ground truth source matrix. A different questionnaire was developed for the evaluator controllers at each location to gather information about what happened during each freeze-frame. For example, the questionnaire for the evaluator controller located with the opposing force addressed the questions in the SA questionnaire concerning the opposing forces. Questions covered such things as how many opposing force were killed during the preceding frame, where the opposing force was located during the proceeding frame, and whether any civilians were co-located with them. The questionnaire for the evaluator controller located with the platoon leader asked questions concerning his location during the previous frame and any orders he may have given during that time. The ground truth questions must be very specific and carefully worded just like the SA questions, or the responses will not always be useful. At least one ground truth question should be developed for every SA question identified in the ground truth matrix as being addressed by the questionnaire.

SA Data Analysis

After the exercise, the data gathered from the ground truth questionnaires and from the instrumentation was used to develop an answer sheet to use in scoring the SA questionnaires. Once the SA questions were scored, the percentage of correct answers was computed for each soldier (Marshak, Kuperman, Ramsey, & Wilson, 1987). Percentages were also computed by level of command (squad leader, platoon leader, and company commander) and by battlefield operating system question categories (i.e., maneuver, command and control, mobility and survivability, intelligence, combat service support, etc.). Chi-square tests were used to distinguish between the baseline and the MOUT ACTD technology SA levels.

Validation of the Metric

Drawing upon the writings of Schneider and Schmitt (1986), the military SMEs analyzed the content validity in conjunction with development of the GDKET measures of effectiveness and with the development of the SA free-play metric. A job analysis was performed by experts participating in the evaluation of content validity and domain sampling was used to represent the behaviors or knowledge skills and abilities found important for success. The free-play metric demonstrated both content and face validity.

Limitations

Several limitations were present during the SA experiments. Because of the nature of the free-play exercise, many uncontrolled variables may have affected the results obtained. These included leadership style, bad weather, late nights, long days, and their potential impact upon troop morale. Also, a free-play exercise involving teams (i.e., other squad members, other squads, and other platoons) does not control for the effect of the other individuals' expertise and motivation upon SA. Last, but not least, the exercises used during the experiments lasted for long periods of time (exceeding 1 hour). There was a desire on the part of the experiment directorate to disrupt the flow of the battle as little as possible. Therefore, only three freeze-frames were executed throughout the entire exercise. This resulted in many SA elements not being assessed.

Conclusion

In this article we sought to describe the development and application of methodologies used to develop operationally based SA measures and assess the contribution of MOUT ACTD technologies to the SA of individual soldiers and small units during free-play exercises. The methodologies discussed in this paper were successfully used to elicit field expedient measures of SA and to assess overall performance of individual and small units during experiments. The freeze frame methodology, in particular, was a valuable tool employed during several MOUT ACTD experiments. It demonstrated the ability to discriminate between baseline and technology conditions and the ability to track a learning curve over time. It also demonstrated both content and face validity. Because the methodology was shown to have merit, it will be used in a large, company-sized, upcoming experiment that focuses exclusively on SA. This experiment will address TTPs for use primarily with intra-squad radios and the contribution of intra-squad radios to the SA of the squad.

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When Theory Becomes Practice: Integrating Scientific Disciplines for Tactical Mission Analysis and Systems Development

Arne Worm

National Defence College, Department of Operational Studies
P.O. Box 27805, SE-115 93 Stockholm, Sweden
Email: TRIDENT@dof.se

The dynamics of tactical missions are of a specific nature. Determined and shrewd exploitation and control of their inherent real-time, safety-critical operational dynamics are vital for success in a wartime or disaster scenario. This paper describes research and development of theories, methods and tools for modeling, analysis and accident prevention in precarious time-critical air traffic control, process control, emergency response and military operations. We performed case studies, field studies, and experiments using a combined systems theory, Cognitive Systems Engineering and psychophysiology framework. We carried out Joint Tactical Cognitive Systems identification, modeling, and synthesis, and investigated inherent command, control, and intelligence activities. We found significant relations between workload, time pressure, cognitive complexity, and physiological stress responses.

Introduction

The Nature of Complex Dynamic Processes and Operations can be characterized as high-risk activities, where human and artificial team members together perform a task, which exacts extreme mobility, efficiency, agility and endurance. In emergency management, air traffic control and military operations mission performance relies increasingly on distributed systems (with many team-players, widely separated, forced to co-ordinate with one another) to attain high safety and effectiveness without risking excessive resource depletion. Commanders and operators will in the future be executing missions with operational and system characteristics that are highly dynamic and non-linear, i.e. small actions or decisions may have serious and irreversible consequences for the mission as a whole. In these kinds of activities decisions and actions are never isolated events. They occur in the context of:

- Stress effects.
- Uncertain evidence.
- Ambiguous information.
- Time pressure and time delays.
- High physical and mental workload.
- Goal conflicts (organizational and social factors).
- Minor actions that can trigger large consequences.
- Highly dynamic and sometimes chaotic environments.

Performing complex, high-risk, tactical operations requires support by highly capable management. High-capacity C^3I support is needed to facilitate omnidirectional, continuous of information flows from the chief executive level to the team-on-site levels. Sometimes individual operators and sensor systems must without delay be allowed to affect decisions and actions of a senior commander. This is beyond reach unless new, cutting-edge solutions can support the humans and systems engaged. The military community calls for ground-breaking approaches to demanding battle management problems. Analogous to this, the art and practice of command and control, tactics, techniques, procedures and training are forced to constantly and concurrently strive for perfection. However, as Rochlin (1997) and others have observed, the specific skills and properties that systems, managers and operators have to possess in order to yield optimal mission performance in such critical and uncertain situations are not easily identified, and hence, they are difficult to improve.

Our underlying principle was integration of well-established scientific disciplines into a pioneering research direction, *Action Control Theory*, a framework specifically composed to facilitate empirically based conceptual modeling of dynamic, complex tactical systems and processes and of their states and state transitions. The resulting models will be used for complex, multi-level human-machine systems design in the military, aviation and emergency response domains.

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The Action Control Theory Framework

Action Control Theory (ACT) is a composite theoretical structure, derived from advances in

I. Cognitive Systems Engineering (CSE).
II. Systems Theory, Control Theory and Cybernetics.
III. Decision Making in Complex Systems Control and Mission Command.
IV. Psychophysiology.

The four research constituting ACT have until now developed along separate paths of evolution. However, now it is time to investigate what they might offer when implemented in an integrated, cohesive and coordinated manner. Flach & Kuperman (1998) concluded that it is essential to develop a unified, proactive, CSE-based approach in research and systems design for future warfare environments. We agree, and hold a strong belief in the power of integrative research approaches:

- Built on solid classical and innovative theoretical work.
- Using comprehensive yet simple and robust conceptual and specific models of systems, tasks and missions.
- Supported by advanced experimental and measurement methods, and data analysis techniques.

Theoretical Constituent I: Cognitive Systems Engineering

The area of Cognitive Systems Engineering has grown steadily since the first significant contributions were published in the 1980s by Rasmussen (1983; 1986), who introduced the concept of skill-based, rule-based and knowledge-based behavior for modeling different levels of human performance. Endsley (1995) developed a comprehensive theory of individual operator, commander, and team situation awareness in dynamic systems. Danielsson & Ohlsson (1996) studied information needs and information quality in emergency management decision making. This work also applies to the military context. Woods & Roth (1988) made a comprehensive review of the CSE domain. Hollnagel & Woods (1983) made a significant contribution to this field by their definition of a *Cognitive System* (CS) as a Man-Machine System (MMS) whose behavior is goal-oriented, based on symbol manipulation and uses heuristic knowledge of its surrounding environment for guidance. A cognitive system operates using knowledge about itself and the environment to plan and modify its actions based on that knowledge. In complex systems this is indisputable. For example, in Command and Control (C^2) tasks in military missions a multitude of sensor systems, communication systems, training programs, personnel and procedures are all elements of the total operational system. Viewing this system as a cognitive system permits the integration of all existing control resources: operators and commanders, technological facilities, doctrine, procedures and training into a coordinated system that can achieve a mission safely and efficiently. The use of CSE to model, analyze, and describe such systems performing hazardous, real time, high-stake activities is a powerful approach, given a sufficient understanding by the investigator of the interdependencies and linkages between other research areas and the CSE field.

Theoretical Constituent II: Dynamic Systems Theory, Control Theory and Cybernetics

By the term *dynamic system* is meant an object, driven by external input signals $u(t)$ for every t and as a response produces a set of output signals $y(t)$ for every t. From the work of Ashby (1956), Brehmer (1992) and many others it is well known that most complex systems have *real-time, dynamic properties*; the system output at a given time is not only dependent of the input value at this specific time, but also on earlier input values, and that a good regulator of a system has to implement a model of the system that is to be controlled. Put otherwise, Ashby's law of requisite variety (Ashby, 1956), states that the variety of a controller of a dynamic system has to be equal to or greater than the variety of the system itself.

An approach based on control theory and dynamic systems can facilitate structuring and understanding of the command and control problem. The mathematical stringency and powerful formalism of control theory makes it possible to describe and treat systems as diverse as technical, organizational, economic and biological dynamic systems in basically the same manner: as processes, or clusters of processes, with a built-in adherent or assigned control system. The concepts of control theory can be used as metaphors in research on decision making, especially in multiple-player, dynamic contexts. The notion that decision making constitutes the regulatory function in command and control processes (Orhaug, 1995) strongly supports the control theory approach. This notion also supports the fact that the hierarchical command structures of military and emergency response organizations are strongly coupled to both centralized and distributed decision making principles (Brehmer, 1988). Annett (1997) used control theory to investigate team skills. This hints at the use of a control theory framework for analysis and evaluation of command and control in tactical operations. Four fundamental requirements must be met (Conant & Ashby, 1970, Glad & Ljung, 1989 and Brehmer, 1992) if control theory is to be used in analysis and synthesis of dynamic systems:

1. There must be a goal (*the goal condition*).
2. It must be possible to ascertain the state of the system (*the observability condition*).
3. It must be possible to affect the state of the system (*the controllability condition*).
4. There must be a model of the system (*the model condition*).

Controlling Joint Systems and Processes
The combined view of control theory in technical as well in behavioral domains is crucial for success in this research area. When a function is implemented at one level of abstraction, represented at a second level of abstraction and controlled at a third level of abstraction the requirement for timely and complete information varies accordingly. On the other hand, it is not important whether a function or mission is carried out by an operator or by an automated system under higher-order supervision, the operators and the supervisory controllers still need to maintain an *adequate situation understanding* – or situation awareness.

If reliable and timely observation and measurement of the system output is unfeasible, and situation understanding cannot be based on the information supplied by the system, it must be based on the current process knowledge and understanding of the situation. Operators and controllers must compensate by means of accurate system performance prediction. This prediction ability is based on the axiom that a cognitive system must be able to think ahead in time and anticipate the dynamics of the process. To accomplish this a cognitive system must solely rely on exact model knowledge of the system input's influence on the system output. This is normally referred to as *open-loop control*. Open-loop control can be a cumbersome and arduous task, especially when the system environment and the mission context is highly dynamic and the system process is unstable and non-linear, i.e. small changes or state transitions in the process can generate an unproportional, unpredictable or even chaotic system behavior. In some cases the disturbances can be measured. It is then possible to almost entirely eliminate the influence of those disturbances by using *feedforward control*. However, this requires extremely good system knowledge of the process that we wish to control. Feedforward control is also sensitive to variability in the system dynamics. The main advantage of feedforward control is the possibility to counteract the effects of disturbances before they are visible as an undesired deviation from the reference. Control theory has proven that although feedforward control can be considered the perfect mode of control, it is often only achievable for a limited amount of time due to *model error* caused by, among other things, the time-constants of the process. However, if the system output can be used to determine the system state, there is only a limited need for detailed knowledge of system dynamics, and *feedback control* can be executed. The necessary adjustments and updates of the controller's internal system model can be made by constantly measuring the deviation of the system output from the reference value. The joint cognitive system is unstable without feedback, and thereby feedback will be needed to correct deviations and compensate for the incompleteness and inadequacy of the internal system model. Reason (1997) emphasized the importance of balance between feedback (reactive) control and feedforward (proactive) control. This concept is crucial to achieve optimal C^2 performance in a tactical mission. Feedforward control is often combined with feedback control because of its practical reliability limitations.

Theoretical Constituent III: Decision Making in Complex Systems Control and Mission Command
Brehmer (1992) suggested the use of control theory as a framework for research in *distributed, dynamic decision making*. The conventional view of decision making, supported by normative theories, reduces decision making to selecting an appropriate action from a closed, pre-defined action set, and to resolution of conflicts of choice. As a consequence, the analysis of decision tasks focuses on the generation of alternatives and the evaluation of these alternatives as in Multi-Attribute Utility (MAU) analysis (Kleindorfer et al., 1993). Research in dynamic decision making has been based on analysis of several applied scenarios, e.g. military decision making, operator tasks in industrial processes, emergency management and intensive care (Brehmer, 1988; 1992). Two things were clarified in these analyses:

1. The decision making was never the primary task. It was always directed towards some goal.
2. The dynamic character of the assigned tasks became apparent in the study of the applied contexts.

These results are consistent with earlier descriptions by Edwards (1962), Rapoport (1975) and Hogarth (1981) of dynamic decision making, which Brehmer (1992) summarised as follows:

1. *A series of decisions is required to reach the goal.* To achieve and maintain control is a continuous activity requiring many decisions, each of which can be understood only in the context of the other decisions.
2. *The decisions are mutually dependent.* Later decisions are constrained by earlier decisions and, in turn, constrain those that come after them.
3. *The state of the decision problem changes*, both autonomously and as a consequence of the decision maker's actions.
4. *The decisions have to be made in real time.* This finding has several significant implications, and they are elaborated upon in the next section.

The real time properties of dynamic decision making cause special problems:

1. *Decision makers are not free to make decisions when they feel ready to do so.* Instead, the environment requires decisions and the decision maker, ready or not, have to make these decisions on demand. This causes stress in dynamic decision making tasks. In order to cope with this stress, decision makers have to develop strategies for control of the assigned dynamic tasks and for keeping their own workload at an acceptable level.
2. *Both the system that is to be controlled and the procedures and resources the decision maker uses*

to control the system have to be seen and treated as processes. Dynamic decision making tasks can be characterized as finding a way to use one process to control another process.

3. *The different time scales involved in dynamic decision making tasks have to be monitored and taken into consideration.* In most situations the active agents in a dynamic system, such as the directly involved operators and their closest commander or squad leader, operate in a time scale of seconds to minutes. Their commanders and their command and control systems operate in time scales of hours to days.

An application of this approach in studies of distributed decision making in dynamic environments such as fire fighting and rescue missions was described by Brehmer & Svenmarck (1995).

Naturalistic Approaches to Decision Making

Zachary & Ryder (1997) reviewed decision making research during the last decades and elaborated on the recent major paradigm shift in decision theory. The shift is from analytic, normative decision making procedures described in Kleindorfer et al. (1993) to Naturalistic Decision Making (NDM), developed and described by Klein (1993a; 1993b), Zsambok & Klein (1997) as well as by Klein & Woods (1993). NDM applies to many dynamic and potentially dangerous areas of activity such as military missions, air traffic control, fire fighting, emergency response and medical care. The essentials of this paradigm are condensed below:

- Human decision making should be studied in its natural context.
- The underlying task and situation of a problem is critical for successful framing.
- Actions and decisions are highly interrelated.
- Experts apply their experience and knowledge non-analytically by identifying and effecting the most appropriate action in an intuitive manner.

Cannon-Bowers et al. (1996) reviewed, commented, and related the NDM approach to the extensive research on Distributed and Dynamic Decision Making described above. They argued that this was how to overcome the limitations of the notions of the classic normative research paradigm in decision making. A fundamental element of NDM, the Recognition-Primed Decision (RPD) model, was presented in detail in Klein (1993a) and was applied to complex command and control environments in Kaempf et al. (1996).

Tactical Team Decision Making

Tactical decision making teams in the modern warfare environment were faced with situations characterised by rapidly unfolding events, multiple plausible hypotheses, high information ambiguity, severe time pressure, and serious consequences for errors (Cannon-Bowers et al., 1995). There were also cases when geographical separation or other forms of distributed environments in which the teams operate impose additional difficulties Brehmer (1991). To be able to adapt to these situations, team members must co-ordinate their actions so that they can gather, process, integrate, and communicate information timely and effectively. This is particularly true of complex systems where it is difficult to assess performance with a single correct answer, or in situations where several individual decision makers who must interact as a team.

Theoretical Constituent IV: Psychophysiology

Within joint cognitive systems performing complex, high-risk military and emergency response missions there is a fundamental and profound connection between human operator physiological stress response and discrepancies between expectancies and experiences. The stress response is an warning of an homeostatic imbalance occurring (Levine and Ursin, 1991). This implies that the concept of *model error* from control theory once again can be applied. The stress response is also mobilizing physiological resources to improve performance, which is regarded as a positive and desirable warning response. The Cognitive Activation Theory of Stress (CATS) describes the phases of the stress response as an alarm occurring within a complex cognitive system with feedback, feedforward and control loops, no less but no more complicated than any other of the body's self-regulated systems (Eriksen et al., 1999). The time dimension of stress responses must be accounted for very carefully.

Models Derived from Action Control Theory

Tactical Joint Cognitive Systems

The point of departure in our ACT-based systems modeling endeavor was the Tactical Joint Cognitive System (TJCS), as the system

- To which a mission is assigned.
- To which the operational command of the mission is commissioned.
- To which the responsibility for effecting the mission is authorized.
- To which the resources needed for performing the mission are allocated.

A Tactical Joint Cognitive System is an aggregate of one or several instances of four principal sub-system classes:

1. *Technological Systems*, for example vehicles, intelligence acquisition systems, communication systems, sensor systems, life support systems, including the system operators.
2. *Command and Control Systems*, consisting of an information exchange and command framework, built up by technological systems and decision makers.

3. *Support Systems*, comprising staff functions, logistic functions, decision support functions, organizational structures, and other kinds of service support.
4. *Tactical Teams*, composed and defined according to (Salas et al., 1992):

> "Two or more people who interact, dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who have been assigned specific roles or functions to perform, and who have a limited life-span of membership."

The concepts of a Tactical Joint Cognitive System are depicted in Figure 1.

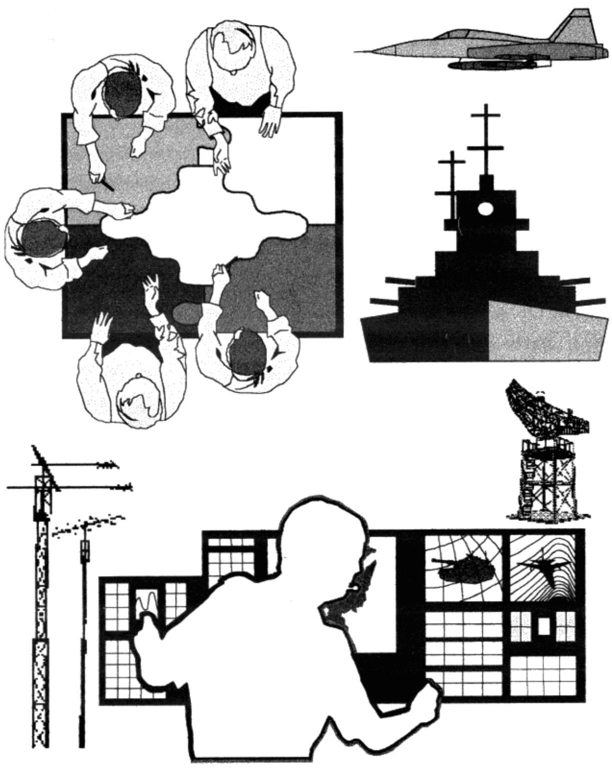

Figure 1. The *Tactical Joint Cognitive System.*

Another important aspect is how the actual mission affects team performance. Serfaty & Entin (1997) drew the following conclusions concerning the properties and abilities of teams successfully performing tactical, hazardous operations:

- The team structure adapts to changes in the task environment.
- The team maintains open and flexible communication lines. This is important in situations where lower levels in a command hierarchy have access to critical information not available to the higher command levels.
- Team members are extremely sensitive to the workload and performance of other members in high-tempo situations.

Tactical Action Control Models

We then turn our attention to the Tactical Action COntrol Model (TACOM, Worm, 2000c), as illustrated in Figure 2.

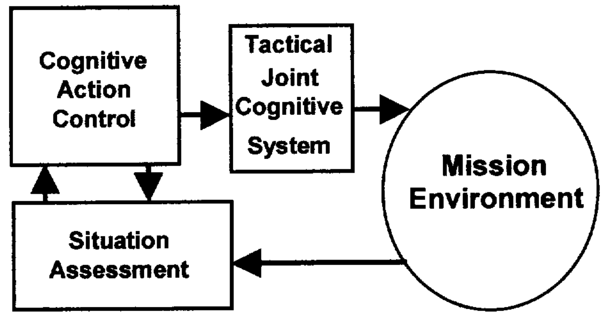

Figure 2. The Tactical Action COntrol Model (TACOM).

The principal components of the TACOM are the Mission Environment, the Tactical Joint Cognitive System, the Situation Assessment function, and the Cognitive Action Control function, derived primarily from the work of Brehmer (1988; 1992), Klein (1993a; 1993b) and Worm, 1998c.

Mission Execution and Control Models

The next step is integration of these concepts into a Mission Execution and Control Model (MECOM), illustrated in Figure 3. The MECOM consists of one or several TACOMs extended with control theoretic components, to handle system disturbances, model error, and to allow an adaptive and balanced mix of feedforward and feedback control.

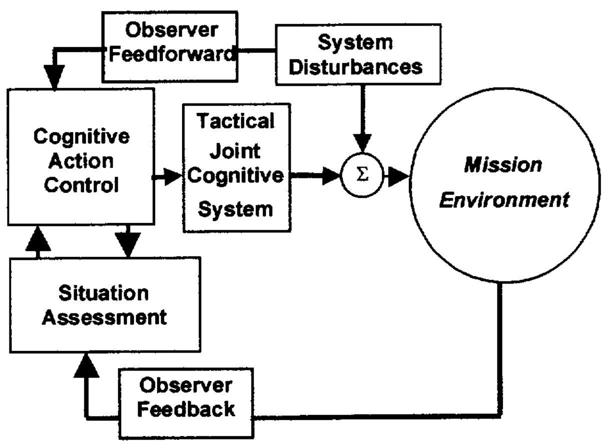

Figure 3. The Mission Execution and COntrol Model (MECOM). This is a simplified version of the full model for greater clarity and for editorial reasons. The full model is depicted in Worm (2000b).

Model Combination and Aggregation
The last step in the model formation process is combining and aggregation of several MECOMs into unilevel and multilevel MECOMs, respectively, as presented in Figure 4.

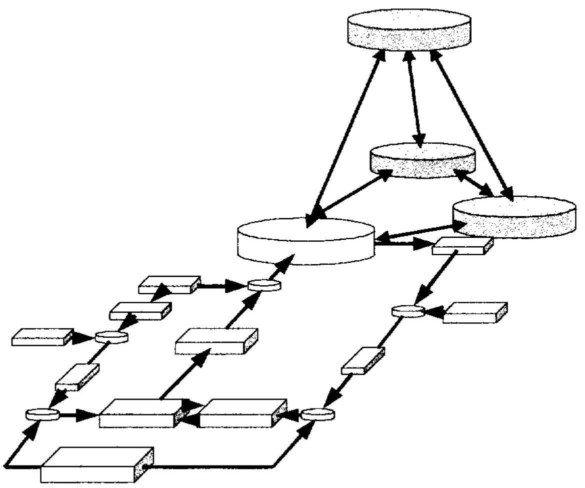

Figure 4. A simplified example of a MULTI-level Mission Execution and COntrol Model (MULTI-MECOM).

Methods: The TRIDENT project

In earlier publications (Worm, 1998b; 1999b; 1999c) we have reported on the progress of the *Tactical Real-time Interaction in Distributed EnvironmeNTs (TRIDENT)* project, aimed at developing a coherent and straightforward package of methods and techniques for man-machine systems analysis in the setting of tactical mission scenarios. The components of TRIDENT are:

- Using the Action Control Theory (ACT) Framework for conceptual modeling of dynamic, complex tactical systems and processes, of their states and state transitions.
- Identification of mission and unit state variables, and of action control and decision making mechanisms for process regulation (Worm, 1998a; 1998b).
- Mission Efficiency Analysis (Worm et al., 1998; Worm, 1999a) of fully manned and equipped units executing full-scale tactical missions in an authentic environment.
- Measuring information distribution and communication effectiveness (Worm, 1998b).
- Measuring workload by means of the NASA Task Load Index (Hart & Staveland, 1988).
- Assessing team member psychosocial mood by means of the Mood Adjective CheckList (MACL, Sjöberg et al., 1979).
- Assessing situation awareness (Endsley, 1995) as a function of mission-critical information complexity (Svensson et al., 1993)
- Measuring level and mode of cognitive, context-dependant control of the team members, and identifying what decision strategies were utilized by the team and team members.
- Applying reliability and error analysis methods for investigating failure causes both in retrospect and for prediction (Hollnagel, 1998).
- Validating identified constructs and measuring their influence using advanced data analytic procedures.

Numerous battle management and emergency response studies have been carried out in which we used every opportunity to test, refine and augment the modeling, measurement, data collection and analysis concepts of TRIDENT. Implementing our ideas for tactical mission analysis in potentially dangerous, stressful and cognitively complex environments showed to be very effective.

Using the TRIDENT concepts for analysis and evaluation on aggregated system levels has so far been very rewarding, with high acceptance among the subjects; trained and skilled professionals performing their daily tasks in their accustomed work environment. However, we have also experienced some critique. It is occasionally claimed that reliability and validity of subjective workload ratings are insufficient. For that reason we considered incorporating a measure of workload and stress which is commonly accepted in the scientific community. We considered hormonal response measures, inspired by the results of Svensson et al. (1993), who studied workload and performance in military aviation, Zeier, (1994) who studied workload and stress reactions in air traffic controllers, and Holmboe et al. (1975), who studied military personnel performing exhausting battle training.

We designed a study in order to elucidate to what extent hormonal physiological stress indications are linked to the rating, observation and data collection methods normally used in TRIDENT to assess workload and tactical performance. The study is described in Worm (2000a), and will be further elaborated upon in a coming doctoral thesis by this author.

Preliminary Results

The main causes of mission failure were information interpretation and distribution failures, due to:

- Slow organizational response.
- Ambiguous, missing or insufficiently disseminated, communicated and presented information.
- Equipment malfunction, e.g. power failure or projectile/missile impact.
- Personal factors: inexperience, lack of team training etc.

Our empirical results through the four-year project life suggest three potentially significant mechanisms influencing how the team is able to execute mission control, which consequently also influences mission efficiency:

1. Time-dependant filtering functions like defense and coping mechanisms according to the cognitive Activation Theory of Stress (Eriksen et al.; 1999, Levine & Ursin, 1991).
2. Dependence on individual mission task requirements (Worm, 2000c).
3. Balance between feedforward and feedback in mission-critical action control (Reason, 1997; Worm, 2000b).

Our theoretical achievements were a complicated and arduous venture, in that we have constantly striven for empirical evidence. Nevertheless we feel that we are approaching a scientific breakthrough. We argue that the ACT / TRIDENT approach will facilitate

1. Identifying limiting factors of a specific individual, unit, system, procedure or mission.
2. Assessing the magnitude of influence of these factors on overall tactical performance.
3. Proposing measures to support, control and improve insufficient capabilities and contribute to successful accomplishment of future missions.

FUTURE WORK

We have for a number of years struggled towards building a foundation for analysis and evaluation of high-stake, life-threatening tactical missions in various work contexts. Although earlier results indicate that we have reached a workable, reliable and valid result, the question is still if our findings are generally applicable. After preliminary analysis of the study reported on in this paper, we contend that studying individuals is a effective, reliable and valid way to probe the function and efficiency of an organization, performing complex tasks in an ever changing mission environment. We will continue to work with the data collected in this and earlier studies, and use the results from the scenarios analyzed to tune and adjust the theory, models and methods in order to obtain a coherent and cohesive framework for human-machine systems analysis of tactical mission settings and scenarios. We will also develop computerized versions of the test instruments, if possible with built-in tools for data analysis and graphical presentation, so that researchers and investigators not familiar with the background and early history of this project can benefit in their own work from our achievements.

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CONSIDERATIONS ON INFORMATION OVERLOAD IN ELECTRONIC WARFARE

Maj.L.CRACIUN
ROMANIAN JOINTSTAFF/J2
1-3 Izvor St, Sect.5
70642 Bucharest
ROMANIA

Summary: This paper presents some considerations regarding the information overload in electronic warfare, focusing on land-based tactical electronic systems. After a quick review of signal environment and signal processing tasks in electronic warfare, two particular cases are presented: emitter identification and evaluation & reporting. For these two cases, some solutions to reduce information overload are considered.

Signal Environment on the Battlefield

The improvements in electronics and computer technologies have made the number of emitters, both civilian and military, increase dramatically. As a consequence, we are facing now a very dense signal environment. The expansion of signals occurs either in space (ground, sea, air and satellite emitters) or in frequency (expansion to the higher frequency bands). Furthermore, the signals in the classical frequency bands have become more complex from the point of view of modulation, coding and other parameters.

By definition, the *signal environment* consists of all the signals that reach the antenna of a receiver, within the frequency band covered by that receiver. Therefore, not only the signals of interest will build up the signal environment on the battlefield, but also the signals from friendly forces, neutral forces and many signals from civilian systems operating in the frequency band of the receiver.

All these signals can be a target for electronic warfare systems, which act to reduce or prevent the hostile use of electromagnetic spectrum, and ensure its effective use by friendly forces. There are many classification criteria used by electronic warfare to divide the signals of interest in different categories, but I think the most suitable for our purpose is the classification criterion based on the destination of the emitter. Using this criterion, the most common types of signals are:

- radio and radio-relay signals
- radar signals
- satellite signals
- mobile telephone signals
- other type of signals

Radio signals can be described by a set of parameters like: frequency, bandwidth, amplitude, modulation etc. Special types of radio signals like frequency hopping signals are described by special parameters: hopping rate, hopping bands, dwell time etc.

Radio-relay signals usually allow transmission of information using more than one channel, therefore an additional parameter can be the number of channels.

Radar signals are generally described by a general set of parameters: frequency, pulse repetition frequency, pulse width and scan rate. Particular types of signals (stagger, jitter, pulse and CW Doppler) need special parameters to be defined.

Satellite signals have become a target for electronic warfare on the tactical field since the satellite tactical systems were extensively used during the latest conflicts. Up-link frequency, down-link frequency, amplitude, polarization, type of information – data, fax, voice – can be only a few parameters to describe the signal.

Mobile telephone signals. Even the signal from a mobile telephone is weak and has a limited range, it complicates very much the signal environment, because of the great number of cellular phones within the area, and the special type of the signal. This mainly applies to low intensity conflicts or special operations taking place in populated areas. Usually, the mobile telephones are not a threat for military systems, but they need to be dealt with, in order to have a accurate picture of the threat

Electronic Warfare Processing Tasks

As we have seen in the previous section, electronic warfare systems have to respond to a very broad band of threats. Therefore, the processing of the information concerning the threat is necessary, before taking the appropriate decision or countermeasure.

The diagram of the processing tasks in a tactical electronic warfare system used for communication

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systems is presented in Figure 1. Each task is described in Table 1.

Processing Task	Role
Search	Continuously scan a designated frequency band in order to detect the threat
Identify	Identify the emitter type by matching the parameters of the threat to the parameters of the library
Intercept	Receive signals from the emitter
Monitoring & Recording	Listening, carrying out surveillance on and/or recording of a particular emitter.
Direction finding	Detection of the bearing of the emitter
Localization	Calculation of the emitter position using two bearings at least
Analysis	Accomplishes the thorough analysis of the signals, mainly for unknown and scrambled signals
Sensor/Data Fusion	Correlate data from multi-source information
Evaluation & Reporting	Evaluates all the searching, DF and analysis reports and issues the Electronic Order of Battle
Jamming	Neutralize the assigned threat

Table 1 Processing tasks and roles for an EW System

The systems accomplishing these tasks are very complex and diverse. A single operator can accomplish one or more tasks. All tasks can be remote controlled, and some can be performed automatically. Search, direction finding, localization, recording can be automatically accomplished. However, for each task the system needs the input from the operator and outputs data to the operator. Some tasks, like emitter identification, analysis, evaluation and reporting need the intervention of an operator, at least to validate the results.

It is beyond the purpose of this paper to present different solutions for data acquisition and processing in electronic warfare systems. The nowadays technologies allow to build hardware equipment and software packages capable of reaching up to 10 GHz/s scanning speeds and instantaneous frequency bandwidth of several MHz in COMINT systems, and several millions of pulse/second capabilities in ELINT systems. These parameters, combined with others (increased sensitivities, large databases etc) allow EW systems to deal with low probability of interception signals, or other kind of exotic signals.

Studies performed on human factors showed that human capabilities have not developed at the same speed as technologies. Training an electronic warfare operator is not so easy, and training a crew is even more difficult, because of the differences among the crewmembers.

One of the most important missions of the electronic warfare is to detect and warn of threats – that means real time reaction. We can reason that the most critical tasks in electronic warfare systems are the tasks that cannot be performed fully automatically using computers and need fast reaction times. Two of them are emitter identification and evaluation & reporting tasks. Let's analyze them one by one.

Emitter Identification

There may be hundreds of radio emitters, dozens of radar emitters and other kind of emitters on the battlefield. Each emitter can have several working modes. If a piece of equipment tried to deal with everything on the battlefield without prior preparation, it would be surely overloaded by the considerable amount of data, no matter how sophisticated is the electronic warfare equipment.

Therefore, every received signal has to be compared with the data stored in the library. If there is a match for enough parameters, the identification is accomplished. If not, the recorded signal is passed to the analysis operator that will have a closer look, using more precise tools and more parameters. These operations are not as simple as they look, because comparison is not always so easy to make. There is an ambiguous nature of the parameters. Sometimes, a tracking radar in the searching mode looks like a navigation radar on the screen. For a pilot, that difference can be the difference between life and death. That's why the operator has to validate the process, after the computer performs the comparison.

The computer plays a major role in the signal identification algorithm, but computers and operators have a different approach to the information. Table 2 shows how they deal with the information flow.

FUNCTION	COMPUTER	HUMAN OP.
Input	Millions pulses/s Thousands of commms signals	Optical input Computer screen
Model function	Fixed format commands	A flexible way of thinking based on experience
Output	Binary data millions bits/s	keyboard (50-200car/min) mouse clicks (60/min) voice
Drawing conclusions	Very specific, based on precise inputs	Perception of the whole electronic environment (even when there is not enough data)

Table 2 Computer and human behaviour in EW data processing

The first and last characteristics are very important when we speak about signal identification. Humans can accept incomplete data and compile it to achieve the complete situation picture. Whenever there is a slight difference between the detected and stored parameters the operator has to decide whether a signal is to be associated with a type of emitter or another, particularly when the computer says there is not sufficient data to give a single and acceptable solution.

Another question is how to avoid the limitation imposed by the limited number of signals that can be processed by the eye of the human operator. In other words, how can an operator identify the dynamic representation of a particular signal on a very cluttered screen. The example shown in the Figure 2 represents a hypothetical screenshot of the signal environment on the tactical battlefield, taken by a fast direction finder system. The receiver system allows the interception of all types of signals including the agile ones. The hints (interceptions) are directly represented on the screen for interpretation and identification. There are about 200 hints from about 50 emitters. It is very difficult for an operator to make the distinction among fixed frequency, frequency hopping, burst and other types of signal. Only a very skilled operator can separate some signals and identify the type of emitter and there is a significant probability of error.

What can be done to help the operator? First of all, the clutter represented by multi-path, mirror and other random signals can be cleared-out using statistic criteria. Secondly, the fixed frequency signals can be isolated using their constant parameters and represented on the screen (white colour). The frequency hopping signals are separated using the bearing information (a significant number of hints with different frequencies are detected on the same bearing -painted in yellow). The rest of signals can be bursts (black) or other types (mobile phones signals, radio-relay signals or unknown). Specific missions require specific signal discrimination algorithms, therefore the process described above has to be very flexible.

After the signal is processed, different types of signals will be represented in different ways on the screen, as you can see in the Figure 3. This will make the life of the operator significantly easier. This way he can concentrate on using his skills to give the solution in case of inconsistency of data. The areas of the screen designated by the numbers 1 and 2 may represent one or two frequency-hopping signal in each case. In the first case the operator has to decide if there are signals from two hoppers close to each other or only from one hopper with some reflections. Similarly, in case 2, there could be two hoppers or a single hopper using two sub-bands.

Evaluation & Reporting

Another critical task in the processing flow is evaluation & reporting. The information received from different component of the integrated system is correlated using also data from other systems and sources and the resulted information is used to elaborate reports for military commanders. According to the Army Field Manual FM 101-5: "*Army operations produce tremendous volume of information. Much of this information is useful, but not pertinent, to the commander, during decision making. Commanders and staff who understand this can avoid potential information overload by using* *effective systems to accurately and rapidly convey information".*

So, only the critical information for the decision making is required during the battle. As the main functions of electronic warfare are to detect, warn of threats and self-protect, a certain amount of EW information is critical for the commander and staff.

Electronic Order of Battle (EOB) is a visualization application, showing in real time the emitters of interest, their level of interest or threat, the allocation of EW resources and the tactical interpretation of the results. Other information of interests, such as the deployment of own troops, communication networks can be also represented. The tactical situation is presented using geographical features as background. Figure 4 presents an example of a simple EOB, using a digital map and an embedded library of symbols. Using a VHF direction finder baseline, close to the Forward Line of Own Troops, the command radio network of the enemy is identified, Brigade HQ and Company HQs were placed on the electronic map.

It is obvious that representing any detail of the tactical situation on an electronic map with plenty of geographical details will make the EOB difficult to read and interpret. There is a practice of using existing software products (former reports, situation displays etc.) and adding new facts and analysis. The result is much more overcrowded picture, with only a small part of information being useful. It is essential that only the up-to-date information be rendered in the report.

Another important problem of EOB is the appearance and options for the geographical features. Sometimes, you need some geographical features to be underlined, while others are obscuring the tactical information.

One solution to the problem is the Geographical Interface Systems (GIS), which use databases to store the geographical data. Digital Chart of the World, (DCW), Digital Terrain Elevation Data (DTED), and VMAP are only a few standards used for digital maps with GIS. Figures 5 and 6 represents a simple comparison, showing the advantages of using a GIS package to generate EOB situation displays.

The example starts from the same picture, representing a shape (ARCVIEW) file, in the Figure 5 (left side). Because the files were exported for the purpose of this presentation, there seems to be no improvement in appearance for a shape file, but in fact it can be loaded faster and require a smaller amount of memory. As geographical information in the shape file is organized in a database any report, graph, diagram or table containing geographical and tactical data is relatively easy to build. You can search for a particular village on the map using its name, you can find distances using mouse clicks, or you can select the peaks having a certain height with road access to install your sensors. There are many displaying possibilities.

Zooming in a bitmap EOB can be a nightmare, while zooming a shape image preserves the clarity and require less time. The comparison is presented in the two pictures from the middle.

The shape maps are organized on layers. One can activate only the useful layer (only one mouse click can activate or hide a layer). The top and bottom right pictures represent the same basic situation. In the top right picture the EOB use only two geographical layers: river and population. In the bottom right side of the screen a new layer was added -railways. The tactical data can be also organized on layers. Labeling allows you to put only the relevant names on the map, by using mouse clicks (in this case only the names of towns and villages close to the military headquarters).

Conclusions

Some practical conclusions can be drawn, based on the above considerations:

- There is an increasing use of computers in processing electronic warfare information on the battlefield in order to surmount the problem of increasing quantity of data, but this does not mean the operators will be completely eliminated from the system. The computers will support the limited human capability regarding input and output data and people will use their flexible thinking to cover the whole situation. This is the way to overpass the information overload

- Visualization technology will continue to be an important issue in electronic warfare, because the people who is involved in decision making is not getting smaller. There are a lot of situations where people need to assess, identify, make interpretation and decisions. Visualization is one of the main ways to prevent information overload.

The standard picture, with an operator in front of a receiver, turning knobs and looking narrow screens is no longer valid. The new technologies, such as VXI, implemented the standard computer interface as human-machine interface in electronic warfare. This allows mission-driven configuration of the EW systems and requires less time to train the operators.

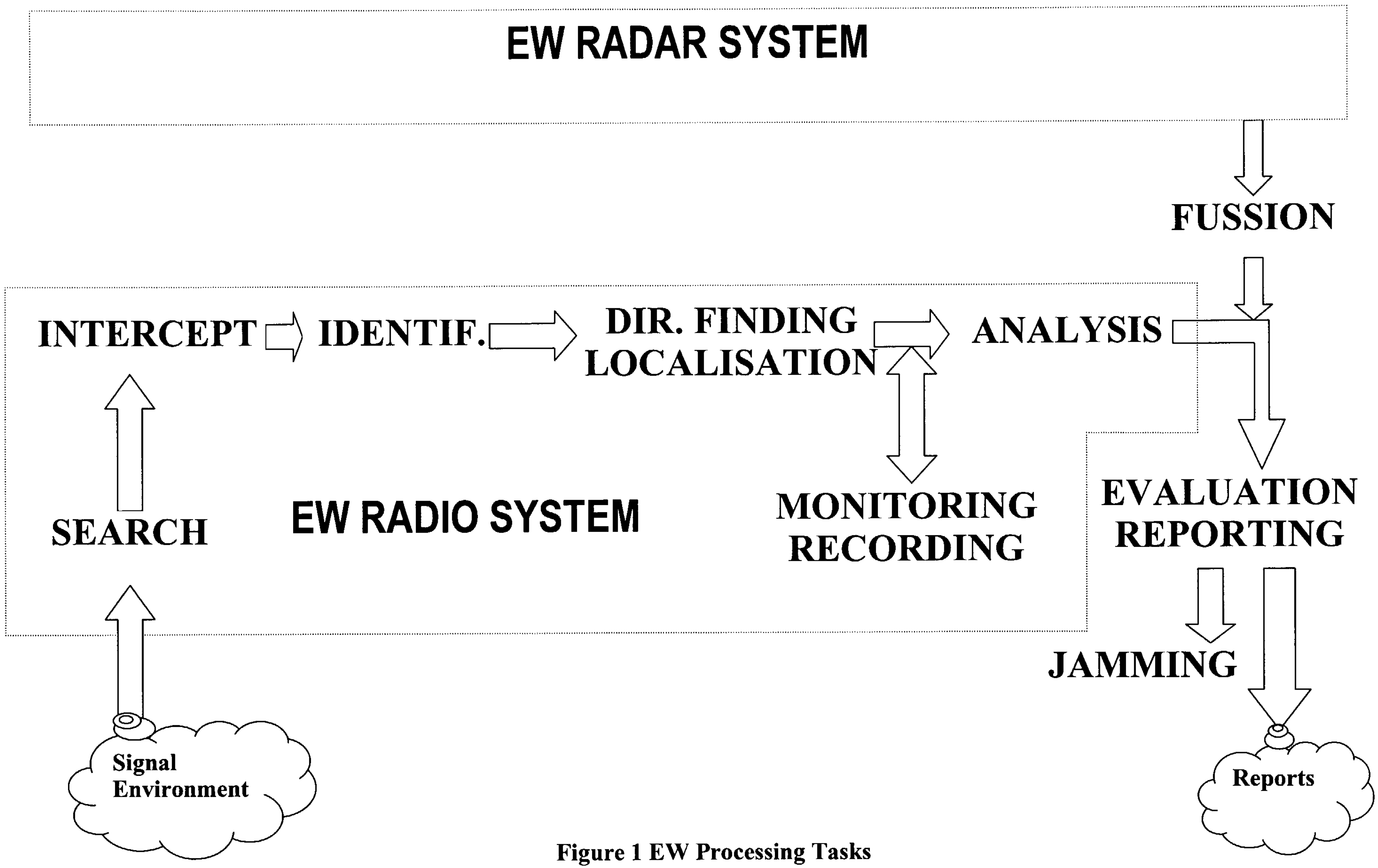


Figure 1 EW Processing Tasks

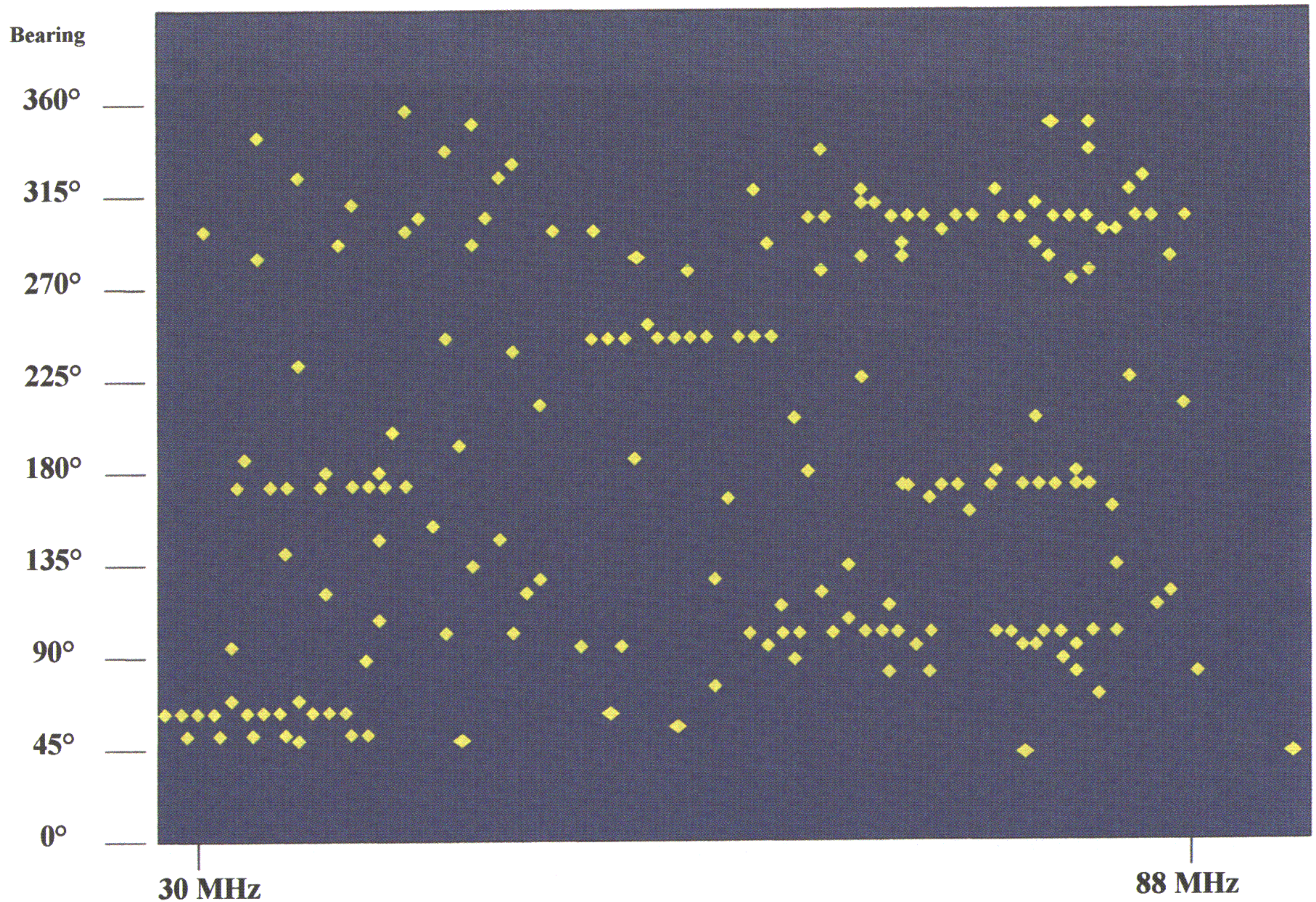


Figure 2 Signal identification without classification

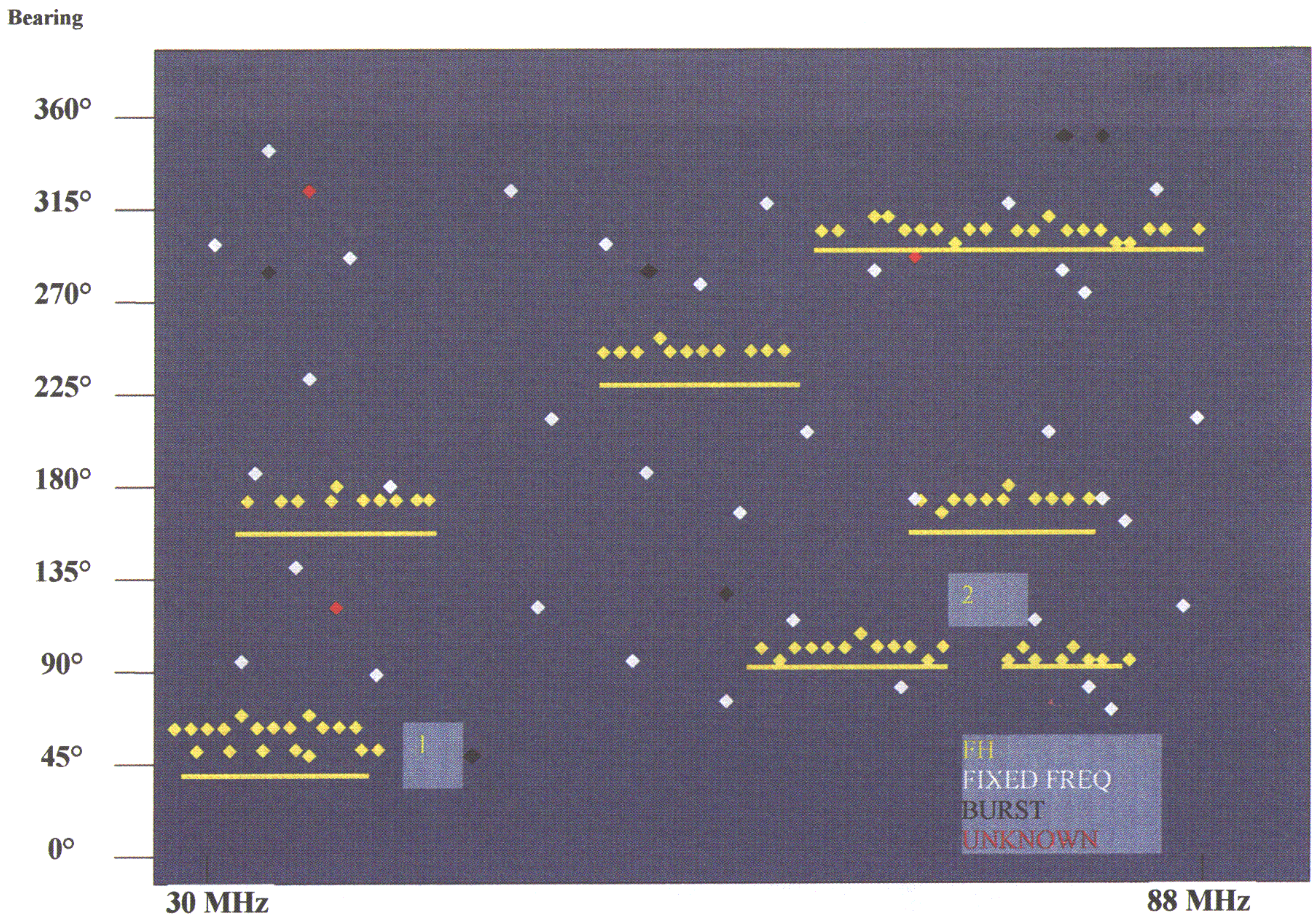


Figure 3 Signal identification after classification

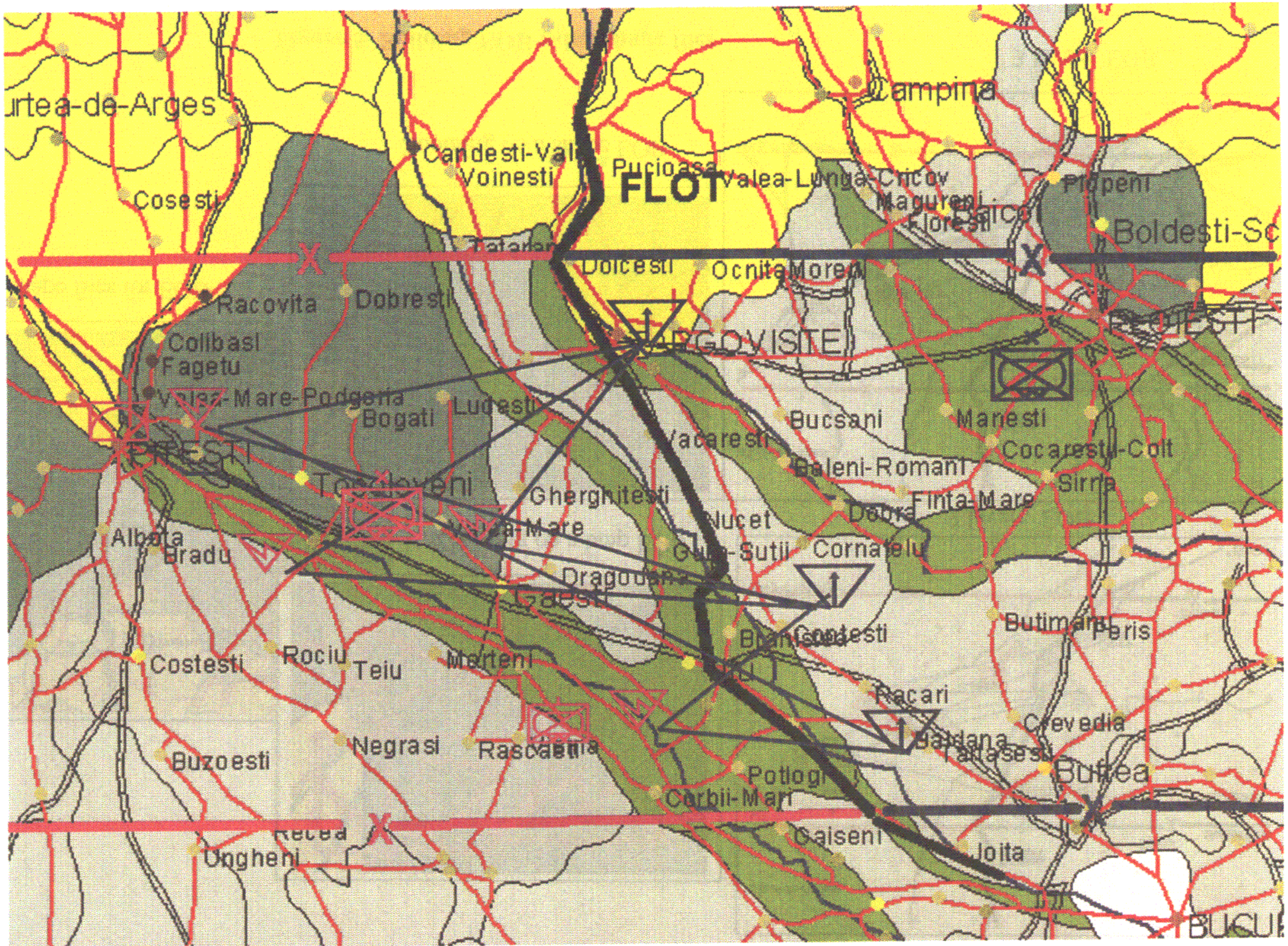
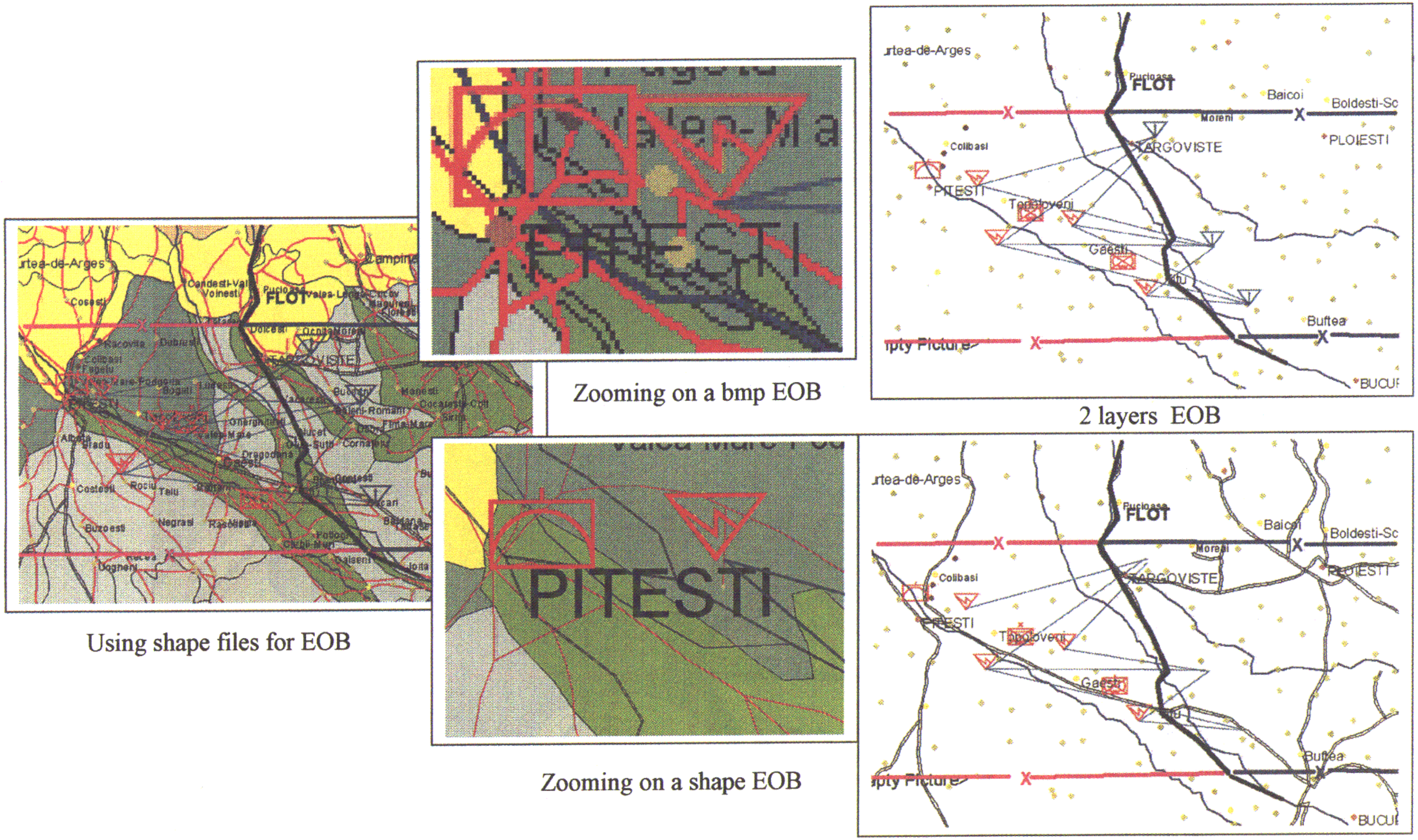


Figure 4 Electronic Order of Battle



Using shape files for EOB

Zooming on a bmp EOB

Zooming on a shape EOB

2 layers EOB

3 layers EOB

Figure 5. Building EOB using shape files

Meeting the Challenge of Providing Visibility of Force Readiness And Capabilities in a Multinational Environment

Mr. William M. Cryan
Joint Readiness and Analysis Division (SAIC Rep),
Operations/Plans Directorate, U. S. Joint Forces Command
1562 Mitscher Avenue, Suite 200, Norfolk, VA 23511
Tel (757) 836-7745, Fax (757) 836-7608, Email cryanw@saic.com

INTRODUCTION

This is a challenging time for the Alliance. What are the true warfighting capabilities of the Alliance? In assessing those capabilities, what metrics is required to assess a unit's joint readiness? With increasing demands being placed on NATO military forces, there is a growing need for Senior Decision-makers to receive more timely, analytical and flexible readiness assessments. Therefore, the Alliance must be able to assess and prioritize missions, essential tasks and operational requirements. This paper examines the challenges of developing and maintaining visibility of force readiness and capabilities within a multinational environment. Alliance and Member Nation/Service policies on force readiness and capability vary widely and often provide only a limited snapshot of a unit's ability to conduct its primary wartime mission and not the actual military operations they are undertaking. The challenge for the Alliance is to maintain readiness to support near-term force requirements as well as the long-term requirements of preparing for future security challenges. While technological advances occur rapidly, changes to readiness policies and reporting procedures move more slowly. This reality is more complex within a multinational environment due to the requirement to extract data from existing heterogeneous, legacy Alliance databases in order to present a coherent view of Alliance forces and their respective headquarters activities.

This paper outlines a technology strategy for visualization of readiness information and for developing a force readiness decision support system for use in a multinational environment to support the monitoring and assessment of Alliance forces with respect to:

- Unit reports (location, status, availability, etc.)
- Determining tactical and operational readiness (personnel, equipment, training and supplies, operations and interoperability)
- Availability of military/civilian airlift, sealift and land transportation assets
- Availability of pre-positioned equipment
- Mobilization capability
- Analyzing operations or contingencies from a force readiness perspective
- "What if" analyses of force capabilities

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BACKGROUND

Maintaining a sufficient level of readiness in today's dynamic political, fiscal, and operational environments presents a significant challenge for the Alliance. NATO is currently in the process of restructuring their armed forces in an effort to create smaller, lighter, more mobile and more rapidly deployable forces. At the same time, however, the Alliance, is engaging in an ever-increasing number of large and small-scale operations. Accordingly, there is an even more urgent requirement for consistent and reconciled readiness data by Alliance commanders and staffs from a readiness visibility and information process and system that will provide:

- An ability to monitor, measure, analyze, and predict the readiness of assigned Alliance forces (e.g., Rapid and Immediate Reaction Forces, Main Defense Forces, Augmentation Forces).
- Access to a timely and accurate readiness visibility and information management system which provides an automated fusion of readiness information.
- An articulation of the cost of maintaining a high state of readiness within the context of small, European-based forces that are being asked to assume ever more increasing and broad requirements.

CURRENT READINESS CHALLENGES FOR THE ALLIANCE

- There are no standardized readiness metrics nor a readiness reporting mechanism within the Alliance that provides the status of each member nation's capability to provide required personnel, combat-capable hardware and technology, appropriate levels of maintenance and spare parts for that hardware, and training to ensure forces can actually conduct assigned operations.
- Readiness information is currently provided through a patchwork of manual and electronic links.
- The Alliance has not implemented an automated system and process to fuse tactical, operational and strategic readiness data.
- Manual readiness analysis is time-consuming and manpower intensive.
- Determining readiness depends on using an agreed to set of metrics against which the forces are measured. Applying varying metrics, therefore, yields varying results. In addition, readiness measurement is often based on subjective assessments.
- While NATO forces are expected to become smaller and more mobile organizations, there have also been major reductions in the number of forces held at high states of readiness. Remaining forces are a mix of both lower readiness units as well as core rapid reaction forces with the result that readiness is now measured in months and weeks, rather than hours and days.
- With smaller forces, a small degradation in readiness is more significant than before. Accordingly, the percentage of "ready" Alliance forces must be larger in an overall smaller total force. In addition, visibility of the readiness of "stay-behind" forces is critical since it is harder to monitor.
- Estimating operational readiness involves aggregating or “rolling up” readiness data from subordinate commands (tactical level) to higher commands (operational and strategic levels). The complexity in assessing operational readiness comes in trying to compare the aggregated data from one service with aggregated data of operational units from two or more other services.

- Developing and implementing an enhanced readiness visibility and information systems is of value only to the extent that it is accompanied by appropriate modifications to doctrine, concepts of operations, and policy and the willingness of the Alliance to integrate them into the operational environment. While the formation of a new NATO Standardization Organization is a good start, progress has been slow in changing doctrine, organization, and incorporating technology to ensure that NATO forces can serve as an effective crisis management tool.

- The gap in modernization and overall force reductions impairs NATO readiness. The Alliance can currently mobilize only a small percentage of its overall combat potential on short notice--a substantial decline since the end of the Cold War.

- Europe may be falling behind the United States in technological capabilities and must depend on the force capabilities of the United States, particularly in the areas of strategic lift, logistical sustainability, and the gathering, processing, and dissemination of intelligence.

DEFINING AND MEASURING ALLIANCE READINESS

Definition. Readiness is a fundamental aspect of an effective armed force and can be viewed as the ability to rapidly mobilize, deploy and sustain trained forces in an area of operations for an extended duration. Discussions of readiness components generally include the following six elements:

- Qualified people
- Combat-capable hardware and technology
- Appropriate levels of maintenance and spare parts for that hardware
- Appropriate tactics, techniques and procedures that support the capabilities represented by the qualified personnel and combat-capable hardware
- Training to ensure forces can actually conduct assigned operations
- The ability to deploy hardware and personnel to the fight

Measurement. In order to assess how ready the Alliance's military forces are, the following criteria can be applied and assessments made based on the results:

- For each measured unit, compare the required numbers of qualified personnel against the numbers actually on hand and available.
- For each measured unit, determine whether adequate supplies and spare parts are on hand.
- For each measured unit, determine and monitor the type and amount of training.
- Determine the ability of the sustaining base and infrastructure to support either major operations or smaller-scale contingencies for extended periods.
- Identify whether the Alliance has developed and promulgated the appropriate TTP for conducting military operations.
- Determine whether Alliance forces move quickly to wherever they might be needed.

- Determine the extent to which bases, hangars, maintenance depots, fuel farms, training ranges, etc. are in an "up" status.

SPAN OF ALLIANCE READINESS

Alliance readiness exists at the tactical, operational, and strategic levels. Readiness visibility and information systems must be able to support assessment requirements at each level.

- **Tactical** level. The level of preparedness of individual Alliance units to execute assigned missions with available weapon and support systems. Are the smallest elements of the Alliance ready to fight?

- **Operational** level. The level of preparedness of senior commands and joint task forces to integrate and synchronize ready combat and support units to execute assigned missions. Can the Alliance effectively form larger, operational-level fighting units from forces of the member nations? Can these organizations operate in coordinated ways with other operational-level units?

- **Strategic** level. The level of preparedness to support the Alliance military strategy. Strategic readiness is determined by senior Alliance military and political leadership by providing the means to put the right forces in the right place at the right time to fight the right conflict. Strategic readiness is based on the aggregation and synthesis of readiness data from the tactical and operational levels and combined with other data such as infrastructure analyses and industrial capabilities.

ALLIANCE READINESS VISIBILITY REQUIREMENTS

In order to assess the readiness of an integrated package of Alliance forces effectively, an ability to access, visualize and analyze the following information is required.

- Unit identification
- Unit capabilities
- Unit sustainability
- Unit's ability to re-deploy and reconstitute
- Hierarchical view of the unit within its component/force
- Unit status (current and projected)
- Mobilization of total force package
- View of major training exercises
- Task Force staff training
- Force interoperability during operations
- Deployment shortfalls
- Cost associated with operations and training

ENHANCING OPERATIONAL CAPABILITIES AND READINESS ASSESSMENTS THROUGH TECHNOLOGY INSERTION

The following proposed technology approach would provide Alliance military analysts and decision-makers with an automated decision support tool with a visualization capability into stove-piped, heterogeneous readiness and deployment databases. The approach must provide a consolidated picture of Alliance readiness data and leverage this information to improve the management of resources. It will also provide a single-point user-pull access to required data. The following are maturing technologies that are directly applicable to the technical challenge of developing and implementing an Alliance readiness visibility system.

- **Joint Readiness Automated Management System (JRAMS).** JRAMS is a user-friendly, readiness assessment tool that accesses, compiles, and displays information from disparate readiness and deployment databases. JRAMS allows military planners and readiness analysts to assess the current availability and preparedness of any combination of forces, supplies, and equipment. JRAMS permits the rapid display of multiple scenarios and allows the user to quickly change from viewing one potential course of action (COA) to another. Users can switch between a graphical (pipes) or text (spreadsheet) view of the data. Through the use of Composable Data Services (CDS), JRAMS is able to access readiness and deployment data which was previously retrieved and tabulated manually but now available from a single graphical user interface. JRAMS is currently transitioning to a three-tier Java architecture that takes advantage of proven technologies such as Java, XML, and HTTP. These technologies are easily applicable to Web browsers since they're the native protocol of the Internet and allow JRAMS to be more flexible and easily tailored to meet the requirements of multiple domains. JRAMS provides quick access to essential information on unit readiness and availability. It also allows planners to explore different options for identifying forces and/or force capabilities for various contingencies. In the past, planners and readiness analysts spent valuable time gathering information to support plan development. Now, less time is used looking for information and more time can be devoted to developing and assessing plans. The system uses "point and click" technology and intuitive interfaces to help users arrange and filter data, accessing unit resource, training and commitment data. The system also has an export capability to a number of commercial off-the-shelf office software for preparing graphic and text reports and briefings. JRAMS enhances the clarity of presenting unit readiness status information by color coding the displays.

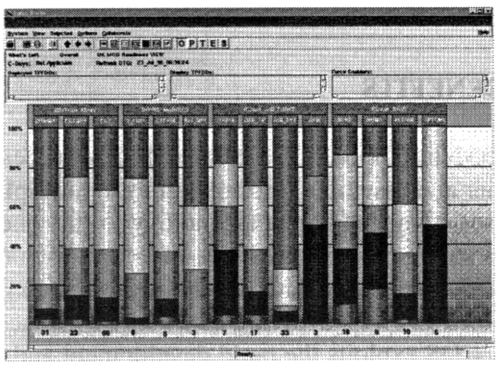

Figure 1 - Notional JRAMS View.

- **TYCOM Readiness Management System (TRMS).** TRMS is a web-based readiness reporting and analysis program that provides a fully integrated environment for online analytical processing of readiness indicators to measure current Fleet readiness, analyze readiness trends, and to facilitate future readiness and resource planning. TRMS has been successful because it provides accurate and timely data, is user-friendly, integrates a variety of different readiness data, provides a common baseline for hardware and software, provides a common baseline for business rules, and eliminates burdensome reporting practices for the Fleet.

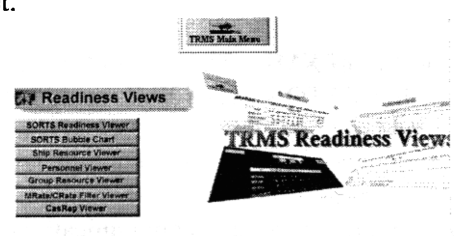

Figure 2 – Notional TRMS Readiness GUI

- **Electronic Watch Board (EWB).** An innovative information visualization capability called an Electronic Watch Board enables multiple concurrent views of up to 16 different individual or combined data sources in a web-based environment. Each of the 16 cells can be tailored to display a variety of analytical graphics to facilitate user review and decision-making; each of the cells is connected to live data and supports a capability to display more detailed data to permit further analysis of the information displayed. . The technologies and languages that can be leveraged in the Readiness Watch Board include object-oriented analysis and design, Java, CORBA, XML, RMI and UML. Users can select data elements for display and customize the graphical views in individual cells in the Watch Board. The user can create pie charts, bar charts, and three-dimensional views to compare and analyze selected data sets.

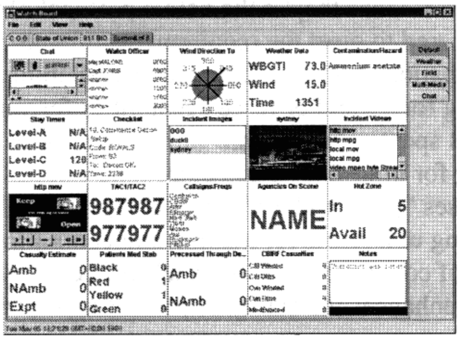

Figure 3 – Notional EWB GUI

GENERAL APPROACH AND BENEFITS

- **Employ Composable Data Services (CDS).** CDS creates the data access and communication infrastructure necessary to gather and assemble information from multiple disperses data sources residing within legacy systems. CDS uses advanced object technology to stay ahead of evolving technology. CDS transforms individual data storage repositories into an information resource. The transformation is accomplished without the need to create large data warehouses or data marts to accumulate the information. Existing data sources and new evolving data sources are accessed through the same common information interface. CDS exploits the rapid development and cost-savings benefits of CDS. CDS will allow the readiness developers to standardize interfaces and specifications so that software built to international standards can be used, evaluated and adapted in ways that make sense to the operational planners and analysts. CDS uses commercial-off-the-shelf tools such as Rationale Rose to define user capabilities, data requirements, and create an object model that represents the business applications and data flow within the system. The Schema Server would provide the data dictionaries and locations of the data elements required by the business applications. The Model Editor would enable the system designer to map data to the services/business applications, and the Code-Generator would automatically generate the underlying services (e.g., query, proxy, naming, and persistence), as well as the client objects of the business applications and graphical displays.

- **Capitalize on the maturity and utility of XML.** The NATO Consultation, Command and Control Agency (NC3A) is examining whether NATO's use of XML could help improve interoperability between heterogeneous (national and NATO) C3I systems. NATO has an ongoing data modeling effort by a data administration organization. It also has an emerging high level technical architecture in which the place and role of XML could be clearly identified. XML is platform independent and allows different computer hardware, software, databases and communications protocols to exchange information. Data content is separated from its presentation format, allowing customized views of data tailored to support specific user requirements. The use of XML will drastically improve the user's ability to find, retrieve, and process and exchange tremendous amounts of information easily across system, organizational and format boundaries.

- **BENEFITS**. The benefits of employing CDS and incorporating proven readiness assessment and visualization tools in this technical approach are:

  - The technology increases the productivity and performance of the developers by providing tools for rapidly integrating large amounts of information from otherwise incompatible systems into a common framework.

  - The developers can focus on application logic and not on data access, plus a reduced amount of time and expertise is required to implement robust services and business applications.

  - The time and cost of development and enhancements are reduced because of the rapidity by which new data sources may be integrated into the common information framework, the elimination of custom coding, and the avoidance of multiple point solutions in complex architectures.

  - CDS promotes a consistent handling of security issues; standard coding requirements, policies, and practices can be embedded within the code-generation process based on defined rules, algorithms, constraints, etc.

PROPOSED TECHNICAL APPROACH

- **STEP 1. Requirements modeling and analysis**. Alliance readiness analysts in the field and at headquarters capture and iterate requirements. Modern COTS tools such as Gensym's G2 tool kit[e] could be used to capture the requirements, processes and relationships; model and assess them within a comprehensive modeling and simulation framework; and engage operational end-users directly in the knowledge capture process because of its simple and intuitive user interface.

- **STEP 2. What-If Analyses.** Once requirements are captured in the tool kit, "what-if" analyses can be rapidly conducted to optimize the desired performance and/or test new concepts conceived by the end-user prior to system implementation.

- **STEP 3. Proof-of-Concept system requirements definition.** This phase would involve identification and description of a core set of requirements and appropriate databases to be accessed, including location, format/content, access methods, specific Information Exchange Requirements (IER), and security requirements.

- **STEP 4. No Re-engineering.** A key aspect of the technical approach is that there is no requirement to re-engineer the databases or consolidate all readiness-related data in a data warehouse because the application of CDS technology would enables the readiness to have direct access to existing databases.

- **STEP 5. Rapid code generation.** The principal value of CDS is that it promotes the rapid code-generation of many object servers (i.e. Java RMI, EJB, CORBA) that can access multiple heterogeneous databases/data sources.

- **STEP 6. Proof-of-Concept system design and development.** Once the core requirements have been defined and agreed to among the Alliance Readiness IPT, the design and development phase would commence. The design and development approach is illustrated in Figure 2 and summarized in the following paragraphs:

- **STEP 7. Iterative definition of future builds/extensions to the core system.** Readiness support applications and data requirements can be rapidly incorporated in the object model within Rational Rose and the Schema Server, and the new system containing both the old and newly designed services and business applications can be quickly code-generated. In addition, legacy databases don't have to be changed and CDS developed applications can rapidly adapt to changes in data format and structure in order to accommodate changes in data requirements.

SUMMARY. From a readiness analysis perspective, the Alliance is grappling with issues that are significantly more complex than the "jointness" and "joint readiness assessment" issues that the U. S. Military has been trying to address for several years. It will be a major challenge to get 19 member nations to agree on standards for readiness reporting or whether to allow Alliance systems to access, aggregate and display national data. Those issues must be addressed; however, in order to provide Alliance commanders and their staffs with consistent and reconciled readiness information to be used in support of current and emerging Alliance military force requirements.

As noted in the beginning of the paper, this is a challenging time for the Alliance. Demands are increasing for use of NATO military forces and Alliance commanders and their staffs must be able to assess and prioritize missions, determine essential tasks and evaluate operational requirements.

- Maintaining a necessary level of readiness in today's ever changing political, fiscal, and operational environments will continue to present a significant challenge for the Alliance. The situation is complicated by the fact that while NATO is in the midst of restructuring their armed forces to create smaller, lighter, more mobile and more rapidly deployable forces, the Alliance is engaging in an ever-increasing number of large and small-scale operations.

- An Alliance readiness visibility and information system should allow for continuous, real-time readiness reporting and analysis throughout the full range of Alliance operating environments from austere deployed areas of operation using commercial telephone lines to standing headquarters locations. The fundamental requirement is for readiness visibility to support operational planning, deployments and exercises.

- To meet this requirement, readiness and readiness related data must be identified, accessed, aggregated, analyzed, comprehended, transformed and delivered. Additionally, the Alliance must place greater emphasis on defining required readiness levels with the appropriate level of resources applied against it. There is a significant difference between the required readiness of a Main Defense Force unit versus more deployable units like the Immediate Reaction and Rapid Reaction Forces.

- The Alliance must be able to strike the right balance between maintaining readiness to support near-term requirements of responding to theater crises and the long-term requirements of preparing for future European security challenges. Accordingly, Alliance members contributing forces must meet NATO requirements for enhanced readiness, mobility, sustainability, survivability and interoperability.

RECOMMENDATIONS

1. Develop and implement a readiness visibility system to allow Alliance readiness analysts and decision-makers to:

   - Extract, evaluate and display data from Alliance readiness and deployment databases.

   - Embed C3I business rules for navigating, viewing and fusing readiness and readiness-related data.

- Develop metrics to support the requirement to integrate and synchronize ready combat and combat support forces to execute assigned missions.
- Enable rapid presentation and analysis or readiness and force capability data and reduce force readiness assessments from days to hours.
- Enable military planners and readiness analysts to perform "what if" analyses and rapidly view the impact of executing one or more force deployment plans.
- Leverage emerging data services technology to provide heterogeneous database functionality and allow the retrieval and display of readiness information from multiple data sources.

2. Establishing an Alliance readiness and force capability assessment system will, of necessity, require changes to existing:

- Policy (to implement a more robust and detailed reporting requirement),
- Technology (to develop a means to access the likely stove-piped data sources of 19 member nations)
- Political will (to allow the Alliance to create a data collection capability that some Member nations may feel is intrusive).
- Determination of standardized readiness metrics for tactical, operational and strategic levels of readiness
- Determination of assessment metrics

3. The Alliance should also consider developing a tool to input data from existing Alliance and member nation/service organizations in order to provide a more consistent view of forces and headquarters activities. The retrieved data presentation should include time, unit, requirement, type of activity and other pertinent categories.

LA VISUALISATION DE L'INFORMATION A LA LUMIERE DES NOUVEAUX CONFLITS

Général Loup FRANCART
Directeur de Recherches
Institut de Relations Internationales et Stratégiques
2, Bis rue Mercoeur
75000 – Paris, France

La visualisation informatique du champ de bataille découle de notre manière de voit dans notre tête les informations que nous supposons utiles. Habituer à réfléchir aux mouvements d'unités sur des cartes, notre conception des besoins de visualisation reste liée à la capacité de les représenter dans le temps et dans l'espace. Il faut maintenant se demander, avec les nouveaux conflits dans lesquels sont engagées les nations occidentales, si cette façon d'appréhender la représentation du champ de bataille reste vraie ou si elle ne doit pas évoluer vers d'autres formes de représentation.

1. Les évolutions stratégiques de la décennie

Dans le contexte bipolaire, nos forces armées étaient préparées à faire face aux violences de guerre des opérations classiques de haute intensité, tandis que certaines unités réservées aux interventions hors Europe connaissaient d'autres types de violence liés aux conflits dits " de faible intensité ".
Depuis une dizaine d'années, la nature intra-étatique des conflits favorise de nouvelles formes de violence dont l'interprétation peut faire l'objet de diverses approches.
Les enseignements tirés des récents engagements montrent que la violence peut relever de six rationalités distinctes. Il conviendra de les analyser en terme de causes, de motivations et d'objectifs. On peut distinguer les **types de violence** suivants :

- violence engagée,
- violence insurrectionnelle,
- violence institutionnelle,
- violence mafieuse,
- violence psychotique,
- non violence.

Par ailleurs, à l'intérieur de chaque catégorie de violence, les actes peuvent être classés par **degrés d'intensité** croissant.

- Au niveau le plus bas, la **violence psychologique**, sans emploi de violence physique, s'exerce par la menace, l'exclusion, ou le mépris ;
- puis une **violence sporadique**, expression intermittente du passage probable à une violence permanente ;
- une **violence ciblée**, dirigée contre des biens ou des personnes supposées représentatives du groupe ou de l'organisme à combattre ;
- une **violence aveugle**, frappant n'importe quel bien ou personne, ayant pour but d'instaurer un état de terreur dans l'opinion publique et qui contraindrait les autorités à négocier ;
- une **violence légitimée** par une reconnaissance internationale ou au moins nationale ;
- enfin une **violence généralisée**, celle d'une guerre ouverte, qui dépasse le domaine de la maîtrise de la violence.

Constatons la survivance des conflits de souveraineté. Ce type de conflits dans le contexte stratégique actuel ne menace plus les intérêts vitaux des pays occidentaux. Il reste cependant plausible dans le cadre d'un conflit régional entre des puissances moyennes s'affrontant pour l'établissement d'une ère d'influence : guerre du Golfe, guerre entre l'Iran et l'Irak, guerre des Falklands. Ce sont généralement des conflits qualifiés de symétriques. Les pays occidentaux ne peuvent s'en désintéresser en raison des risques importants de déstabilisation d'une région du globe et des menaces qu'ils peuvent faire peser sur les intérêts stratégiques occidentaux. Ils utiliseront alors leurs forces armées pour imposer aux antagonistes le retour à la paix ou le règlement pacifique des différends.
On peut aussi observer l'importance prise par les conflits identitaires. Ce type de conflit est souvent dissymétrique. Le pouvoir appartenant à la culture dominante dispose généralement de forces

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constituées, police et armée, organisées à la manière occidentale et dotées d'armements plus ou moins sophistiqués. La violence s'exercera des deux côtés de manière différente. L'un par l'abus de la force publique, l'autre par des moyens et des modes d'action adaptés aux réseaux d'opinion, de logistique, d'armements, de relations. Au terrorisme des uns répond la terreur exercée par les autres, à l'occupation répond la guérilla... Il arrive aussi que ces conflits soient symétriques. De nombreux conflits africains ont été des conflits quasi-symétriques, avec des moyens et des voies assez semblables, pourtant très éloignés de notre vision occidentale de la guerre.
Dans la plupart des cas, les forces occidentales se pose en tiers (s'inter-pose) par rapport à des belligérants ou auteurs de violence. Il s'agira de modérer le conflit, maîtriser la violence, mettre en place les conditions nécessaires à la résolution politique du conflit. Ce concept d'intervention ne doit pas être ramené à celui d'opérations de maintien de la paix instaurée par l'ONU. Dans de nombreux cas, il sera nécessaire de recourir à la force pour faire respecter les termes du mandat, mais celle-ci devra toujours éviter la bascule dans la guerre avec un ou des belligérants.
Ainsi, le cadre particulier des opérations de maîtrise de la violence se situe plutôt dans les conflits d'identité, intra-étatique et en interposition, c'est-à-dire sans adversaire désigné. Mais ce n'est qu'une approche générale. Le cas des opérations de contre-insurrection, par exemple, se situe dans le cadre d'un conflit soit identitaire, soit idéologique, intra-étatique, sur le territoire national, dont les auteurs sont bien des ennemis identifiés et qualifiés comme tels.
Comprendre les conflits pour y apporter des solutions est une nécessité pour les nations occidentales. La mondialisation les contraint à se donner un rôle nouveau de pacificateurs : « empêcher la guerre ». Si, dans le passé, il est arrivé à certains pays de jouer ce rôle aux marges de leurs zones d'intérêts stratégiques, jamais cette idée n'avait obtenu un tel consensus entre plusieurs pays. En parallèle aux buts politiques et aux objectifs militaires des guerres inter-étatiques toujours possibles, doivent maintenant être pensés les buts politiques et les objectifs militaires recherchés en intervenant dans les conflits intra-étatiques. Dans ce cas, les forces mandatées ne cherchent plus à s'opposer militairement aux combattants. Elles cherchent à éviter la prolongation de la violence et à permettre la mise en place d'une solution politique.
Cette approche est nouvelle pour les militaires. Née d'une vision tactique de l'emploi des forces, propre au contexte de la guerre froide, leur approche des conflits est restée très clausewitzienne. Certaines notions théoriques de Clausewitz demeurent pertinentes. La guerre reste la continuation de la politique par d'autres moyens. C'est bien l'emploi qu'en font les belligérants et acteurs de violence. La fin politique recherchée par l'engagement militaire pour s'opposer à la violence consiste toujours à imposer une volonté politique, mais dans le sens de la paix et non plus par l'anéantissement des belligérants.
Si, comme le concevait Clausewitz, l'engagement reste un duel, il s'agit désormais d'un duel des volontés, c'est-à-dire de ce qu'Edward Luttwak appelle "*le duel des esprits directeurs*". Il n'atteint pas et n'autorise pas le duel des armes, au moins au niveau stratégique.

2. Les conséquences sur la représentation de l'espace

L'option stratégique maîtrise de la violence implique une surveillance et un contrôle très poussés des espaces composant le théâtre d'opération. Par la maîtrise de ces espaces, le commandant de niveau opératif doit être en mesure de restreindre la liberté d'action des acteurs de violence.
Dans les opérations classiques, les armées utilisent l'espace physique comme support et enjeu essentiels de la manœuvre. Dans les opérations de maîtrise de la violence, ces rapports entre la manœuvre et l'espace perdurent. Mais ils se complexifient par une implication plus profonde de l'aspect humain et organisationnel de l'espace. Celui-ci n'est plus seulement support ou enjeu, il se fait acteur. Evolutif, façonnable, il devient une réalité vivante impliquée dans l'action. Sa connaissance, les rapports des unités de la Force avec chacune de ses parties, engendrent la manœuvre elle-même. Sa maîtrise conditionne la possibilité d'empêcher l'escalade de la violence. L'action directe sur les belligérants constitue souvent un épiphénomène au sein d'une gestion globale de l'action dans l'espace.

- ***Les espaces physiques.***

Les espaces aériens et maritimes forment des milieux à peu près homogènes. Véritables espaces de combat dans les conflits symétriques, ils sont surtout des lieux de transit ouvrant accès au théâtre terrestre dans les opérations de maîtrise de la violence.

L'espace terrestre est plus complexe en raison de son hétérogénéité. Il est d'abord physique et écologique. Sa complexité est toujours apparue comme une contrainte majeure pour les opérations militaires. Il est dans le même temps malléable, contrairement aux espaces aériens et maritimes. De ce fait, il est à la fois support et enjeu de la manœuvre. C'est sa morphologie qui guide la réflexion du stratège ou du tacticien.

- ***Les autres dimensions de l'espace géographique***

A coté de l'analyse de l'espace physique terrestre, dans lequel les acteurs de violence vont s'organiser pour survivre et se développer, il devient nécessaire de raisonner la manœuvre dans l'espace humain, lieu d'identités et de cultures, sources des antagonismes territoriaux, et dans l'espace structurel, lieu d'organisation de la vie politique et économique.

L'espace humain s'incarne, en effet, dans la notion de territoire, espace de vie, de rationalité et d'intuitions. Cette notion regroupe : l'espace vécu, lieu social d'une communauté, et l'espace de représentation, ensemble des aspirations historiques et géographiques de cette communauté.

Insistons sur ce dernier point. Il est fréquent qu'une communauté soit insatisfaite de l'espace physique ou politique occupé. Comprendre la vision qu'elle entretient de ce que devrait être son territoire idéal permet de pénétrer la dimension psychologique du conflit et de comprendre les symboles et les valeurs attachés au territoire pour lequel seront consentis les sacrifices communs, et au nom duquel sera justifiée la violence la plus barbare. Elle permet aussi de prévoir les lieux d'affrontement à venir qui correspondent généralement à des positions géographiques clés ou des lieux symboliques.

L'espace structurel comprend l'espace politico-administratif, lieu des luttes de légitimité, et l'espace économique, domaine des flux d'approvisionnement, d'énergie, d'armements, de financement des activités de guerre.

- ***Les réseaux.***

Les réseaux constituent le tissu réel d'un territoire. Ils rendent vivantes les relations entre points et lignes de chaque espace par l'intervention d'acteurs humains les utilisant ou les créant. Ces relations sont variables et organisent les flux circulant entre les points. Il sera toujours nécessaire, pour une force militaire qui agit dans l'espace terrestre, d'identifier les réseaux et d'en définir les relations.

Les réseaux de l'espace physique sont facilement identifiables. Ils tiennent une place importante dans l'analyse des facteurs de l'action militaire et dans l'élaboration de la manœuvre, en termes de mobilité, contre-mobilité et points clés à contrôler. Ils comprennent principalement les réseaux de communication naturels dictés par le relief.

Les **réseaux de l'espace structurel** sont aussi facilement identifiables lorsqu'ils sont physiques. Ce sont des réseaux de circulation de biens matériels ou de personnes. Ils sont contrôlables au niveau des points de communications (gares, aéroports, carrefours...) ou au niveau des points de production et de contrôle (énergie, eau). Leur sécurité globale est plus difficile à garantir. Les réseaux d'information constituent une catégorie à part. Ils sont localisables en termes de moyens matériels (télévision, radio, bases de données informatiques, etc.), mais beaucoup plus difficile à cerner quand il s'agit de réseaux d'influence. Il en est de même des réseaux financiers institutionnels ou informels (diasporas).

Les **réseaux humains** sont moins facilement identifiables, car très mouvants. Un groupe n'est jamais une collection de pions indépendants les uns des autres. Il constitue un réseau qui s'appuie sur des infrastructures matérielles et qui dispose de composantes sociales. Certains des rapports qu'il tisse sont provisoires et disparaissent rapidement, tandis que d'autres sont institutionnalisés : organisation, partis, églises, associations, etc. Les problèmes de conscience collective sont donc éminemment géographiques. Raisonner en terme de réseau signifie raisonner en terme d'interactions. Dans le cadre d'opérations de maîtrise de la violence, la connaissance de ces réseaux humains est indispensable. Le contrôle de certains d'entre eux se révèle facteur de succès important. La dissolution de quelques-uns est parfois nécessaire, tels les réseaux de financement de factions, les réseaux logistiques, les réseaux de circulation des armements.

Ancrés au sein des populations, liés à l'existence du territoire en tant qu'espace vécu, ces réseaux constituent une des clés de l'exécution de la mission.

3. La maîtrise de l'information

La capacité de communiquer et d'échanger des informations est au cœur même de la résolution des situations conflictuelles. Elle requiert la maîtrise complète des réseaux de communication, des échanges effectués et des effets de ces échanges sur le contexte. La situation conflictuelle peut être considérée comme une perturbation d'un vaste réseau de réseaux dont il faut rétablir la stabilité ou en créer une nouvelle. La maîtrise de l'information au sein de ces réseaux est donc un moyen d'action primordial pour ceux qui sont chargés de ramener la paix soit par la maîtrise de la violence soit par des actions de force.

- ***L'information est action et donne du sens***

L'information est devenue action. Elle crée le contexte lui-même, le fait évoluer et ne se distingue de l'action en général que parce qu'elle vise plus directement le plan des représentations. Le contexte est la cible même des actes de communication. Ceux-ci le précisent, l'évaluent, le transforment.

- ***But de la maîtrise de l'information***

Maîtriser l'information, c'est ainsi accéder à une certaine transparence du contexte en identifiant l'ensemble des réseaux dans les différents espaces ; en déduire une connaissance la plus précise possible de la situation ; anticiper les situations à venir et l'évolution du contexte dans ses différents réseaux et espaces ; décider d'une stratégie ou d'une manoeuvre grâce aux moyens d'aide à la décision ; conduire les actions dans les champs physiques grâce à l'information numérisée et donner du sens au contexte en utilisant la communication opérationnelle, la communication médiatique, les opérations psychologiques si nécessaire. L'ensemble de ces activités converge vers la situation future recherchée, définie au moment de la décision d'engagement de la Force. C'est celle-ci qui donne le sens de l'action et de la communication.

Mais en corollaire, maîtriser l'information, c'est aussi, selon le type d'opérations, opacifier le contexte pour empêcher adversaire ou belligérant d'en acquérir une claire connaissance, de le comprendre et d'anticiper les actions menées ; assurer la sauvegarde des systèmes et la sécurité des informations qui y circulent (systèmes de recueil de l'information, de communication, d'aide au commandement, systèmes d'arme) ; enfin, empêcher, dans les champs immatériels, le développement de " contre-sens " favorables à ceux-ci.

- ***Le renseignement***

La notion de "transparence du champ de bataille" qui hante les états-majors depuis quelques années en raison des capacités d'acquisition des systèmes militaires, ne doit pas faire perdre de vue que, dans le contexte de la maîtrise de la violence, le problème de l'acquisition du renseignement est assez différent. Quels renseignements doivent être recherchés ? Il s'agit bien de toujours chercher des indices et des données, mais sur quoi ? Il peut ne pas y avoir d'organisations au sens de structures armées ; s'il y en a, elles ne disposent pas forcément de matériels et de personnels identifiables. Leur fonctionnement peut ne pas être hiérarchisé ou tout au moins peut ne pas se décomposer en strates successives dont chaque niveau dépend hiérarchiquement du niveau supérieur. Dans de nombreux cas, les acteurs de violence vivront et agiront au sein même des populations et ne s'en distingueront pas forcément. Enfin, leurs activités seront parfois difficilement identifiables, car elles ne consisteront pas en actions de combat.

Le renseignement a changé d'objet, il s'est élargi, mais il existe et demeure indispensable à l'action.

En ce qui concerne le renseignement opérationnel et en dehors du renseignement concernant les acteurs de violence, l'action de la Force nécessite l'acquisition de nombreux autres types d'informations. Ces informations sont celles qui ont toujours été nécessaires aux forces pour se déployer sur le terrain et y agir. Elles concernent principalement l'espace physique et la situation des unités.

. Le renseignement terrain, nécessaire aux déplacements et aux déploiements, comme aux diverses tâches de combat ou de contention. Ce renseignement nécessite de nos jours une unité spécialisée de géographie dont la tâche sera d'établir ou d'améliorer les cartes numérisées indispensables aux traitements des informations. Il est également donné par d'autres unités spécialisées (détachement de reconnaissance du génie) ou toutes armes.

. Le renseignement météo.

. Le renseignement d'infrastructure, qui concerne les possibilités de déploiement et de mouvements, ainsi que les conditions d'exécution de la logistique.

. Le renseignement de situation de l'ensemble des unités participant à la force.

Ces besoins étant connus et maîtrisés, ils ne seront pas explicités.

Le renseignement d'environnement peut être considéré comme distinct du renseignement opérationnel par le fait qu'il est recherché, acquis, dans des domaines autres que militaires et fourni par des sources qui ne sont pas nécessairement militaires. Il concerne principalement l'espace humain avec la connaissance des communautés (en particulier les aspects psychologiques qui y sont liés) et structurel, c'est-à-dire politico-administratif et économique.
Le renseignement d'environnement comprend trois domaines principaux :

- Le renseignement concernant « la vie de la cité » : Il s'agit là du renseignement nécessaire à la restauration de la normalité publique et de la vie politique. Il comprend les informations nécessaires à la compréhension de la vie politique locale et des acteurs politiques, les informations sur les médias, les administrations les forces de sécurité (police, gendarmerie, etc.).
- Le renseignement concernant la vie économique : Il comprend les informations sur les problèmes écologiques (sécurité et pollution), les réseaux et systèmes de communications, les réseaux d'énergie, les circuits commerciaux, les fournisseurs logistiques.
- Le renseignement concernant la vie privée : Il rassemble toutes les informations nécessaires au rétablissement d'une vie privé normale et comprend des aspects très variés tels que l'attitude psychologique des communautés vis-à-vis de l'action de la Force, l'état des biens de première nécessité, l'état de santé et les mesures à prendre, les campagnes d'information à mener pour lutter contre accidents liés à la situation de guerre (mines, snipers, etc.), l'organisation de l'aide humanitaire, etc.

Conclusion

En conclusion, la visualisation de ce qu'il est convenu d'appeler le champ de bataille, ne peut plus être conçu comme elle l'était dans les conflits symétriques où des forces armées s'affrontaient.
L'informatique est une aide précieuse et peut permettre de prendre en compte instantanément les données multiples et variées dont on a besoin.
La difficulté réside plus dans un changement d'optique et de mentalité sur l'objet de la focalisation que sur la mise en œuvre technique. Il appartient aux opérationnels de se remettre en cause dans leur visualisation des informations. Les techniques maintenant utilisées sur Internet devraient permettre assez facilement d'opérer cette évolution : recherche par mots-clés, liens hypertexte, utilisation de couches d'information, etc.

The Electronic Sandtable: An Application of VE-Technology as Tactical Situation Display.

Thomas Alexander
Klaus-Peter Gärtner

Research Establishment for Applied Science (FGAN)
Research Institute for Communication, Information Processing and Ergonomics
Dept. Ergonomics and Information Systems
Neuenahrer Straße 20
53343 Wachtberg-Werthhoven / Germany
Tel.: +49 228 9435 –480
Fax: +49 228 9435 –508
email: alex@fgan.de, gaertner@fgan.de

SUMMARY

In future battlespace scenarios huge amounts of highly dynamic information will be available due to the technical development of sensor, communication and information systems. This flood of available information may lead to mental overload of the military commander and cause a wrong mental model of the battlespace situation. Therefore advanced techniques for supporting the military commander and displaying complex tactical situation data in a clearly understandable way have to be developed and evaluated.

At the Research Institute for Communication, Information Processing and Ergonomics (FKIE) of FGAN a concept for preprocessing and visualizing incoming tactical data and three-dimensional geographical data has been developed. The concept includes the use of Virtual Environment-technology as a display system. This "Electronic Sandtable (ELSA)" testbed, as described in this paper, is based on a semi-immersive display technology. It facilitates a plastic stereoscopic visualization of three-dimensional data. It has been developed to be used to simulate a sandtable as commonly used by the Armed Forces for tactical education and training.

This paper presents the baseline concept of using VE-technology as an advanced tactical situation display. It is pointed out that, although the technology is commercially available, research in the area of ergonomics and human factors is essential for the advantageous use of such a system. The main ergonomic topics described in this paper include the stereoscopic visualization of the geographic and tactical data, the degree of abstraction and human operator interaction with the virtual scene on the "Electronic Sandtable".

1 Introduction

Within the scope of future scenarios there will be a high demand on detailed and highly actual information in military command and control (C^2). The demand will be met by complex information databanks, new sensor technology and fast electronic communication structures. Broad data acquisition, transfer and presentation will enable the military commander to get a variety of diverse information about the battlefield situation. The accomplished information dominance is more and more considered to be essential for a battlespace dominance.

However, the massive quantity of information is also hazardous. Especially in time-critical situations when tactical decision making under stress is required, relevant information may be overseen and a wrong mental model of the tactical situation is gained. That overload is likely to be reduced by using new technologies for data preprocessing and data presentation. Because data presentation is of critical importance in the whole process of decision making, ergonomic research is required to analyze the whole process of data presentation, considering new displays and interaction devices.

Especially using Virtual Environment (VE)-technology is promising. It was found to have high potential in presenting and interacting with complex amounts of data. Therefore VE will increase the clearness and intelligibility of a complex tactical situation. The situation scenario is not perceived as a complex of abstract information but as a pseudo-realistic model landscape. This is intensified by an intuitive, easy to learn interaction with the included objects.

2 Definition of Virtual Environment (VE)

The basic idea of generating and using a computer-generated artificial reality was mentioned first in science fiction literature at the middle of the 20th century. Due to rapid development of computer technology in the second half of the last century, a partly realization of this idea became possible. Nowadays these VE-Systems are commercially available and starting to be used for a broad range of applications (Alexander et al, 1999).

According to Bullinger et al (1997), Virtual Environments (VE) describe the computer-based generation of an intuitively perceivable and experiencable scene of a natural or an abstract environment. It is characterized by capacities for multi-modal, three-dimensional modeling and simulation of objects and situations. A further characteristic is the close interaction of the human operator with the system .

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In this connection, Virtual Reality (VR), has been defined by NATO HFM-021 (n.n.) as

> *"... the experience of being in a synthetic environment and the perceiving and interacting through sensors and effectors, actively and passively, with it and the objects in it, as if they were real. Virtual Reality technology allows the user to perceive and experience sensory contact and interact dynamically with such contact in any or all modalities."*

This definition of VR which is often used as a synonym to VE overlaps with VE. But whereas VE is application oriented, VR describes, strictly speaking, a total model of the reality, including all manifold facets of it. As this is not possible today and may not be possible in future, the further article will be use the term VE.

VE can be divided into at least three groups (Bullinger et al, 1997):

- *full-immersive VE* is characterized by a complete replacement of the reality by the virtual reality. The operator is completely included in the virtual world and does not perceive any (visual, acoustic) stimuli from the real word. A head-mounted display (HMD) is a typical full-immersive display.
- *semi-immersive VE:* The virtual scene is presented as a three-dimensional part of the reality. The operator perceives stimuli from the real world and additional stimuli from the virtual world. He cannot distinguish between real and virtual objects. Typical semi-immersive VE-Systems are workbenches which will be described later, and flight simulators.
- *Desktop VE:* The three-dimensional scene is presented on a two-dimensional display medium. Just interaction and navigation happen more intuitively. VRML-Browsers and Videogames work like this.

VE-systems are on their way of becoming used for different applications. Further information about military applications is given in Alexander et al (1999).

First, VE is a *research topic* itself. This involves basic research studies in computer science as well as interface design and ergonomics.

Secondly VE is used as a *research and development tool.* In this area VE Systems enable a very intensive and direct interaction with complex and abstract data. They enable new kinds of rapid prototyping. In an early stage of the design process CAD-models of products can be visualized and examined as if they were real. Improvements can be performed easily in real-time and the effects can be visualized immediately. This bring along advantages for the amount of time, the quality and the cost of the development cycle. In Fig. 1 an example for a virtual walk-through in the design process of a marine vessel's combat information center (CIC) is shown.

Another application is *teleoperation and telepresence.* This is not limited to remote control of unmanned systems. Moreover the operator gets the subjective feeling of really being there. This may enable higher situational awareness which is considered to be advantageous for this application. Furthermore, teleoperation is supposed to be useful for control of robots in contaminated areas, space or deep sea and special military purposes (reconnaissance, surveillance).

Finally, the area of *education and training* is a field of application. In contrast to conventional virtual simulation and simulators VE-systems are more flexible and adaptive. This is because one single VE-system can be used to simulate different types of vehicles or aircrafts. Moreover, training of individual soldiers' skills as well as team training become possible.

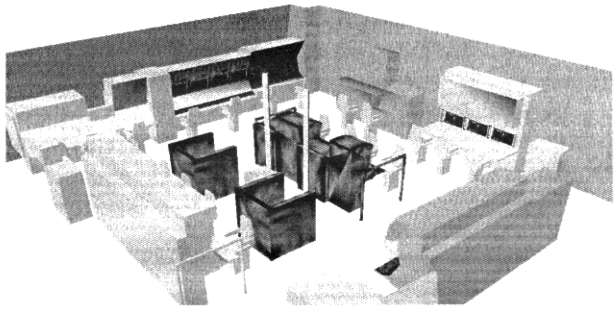

Fig. 1: Virtual combat information center (CIC)

The benefits of VE which have been shown in current approaches in these areas, make it a promising tool for further applications. One of these applications is a tactical situation display (TSD) of a Command & Control system.

3 Tactical Situation Displays (TSD) today

The basic function of TSDs is to display the current situation of own and reconnoitered enemy troops and facilities in the operation area to the commander of a military unit. Moreover the TSD is used for tactical planning of intended future operations. Quantity and quality of situation data are essential for an adequate operation planning (Grandt et al, 1997).

Today there are basically two different types of TSD's used by the strike forces.

The first one, shown in Fig. 2, is a *command post in the field.* The TSD used here works by means of paper & pencil. Actual information is transmitted by radio or field telephone and drawn into a map. It is obvious that in time-critical processes with large amounts of rapid changing information this leads to an overload of the operators. Furthermore, the display may not show actual or valid information and causes errors in decision making. However, it brings along the advantage that the commander is in the field: He gains high situational awareness, experiences the terrain, cover, weather, etc. and knows "what is really going on" at that place.

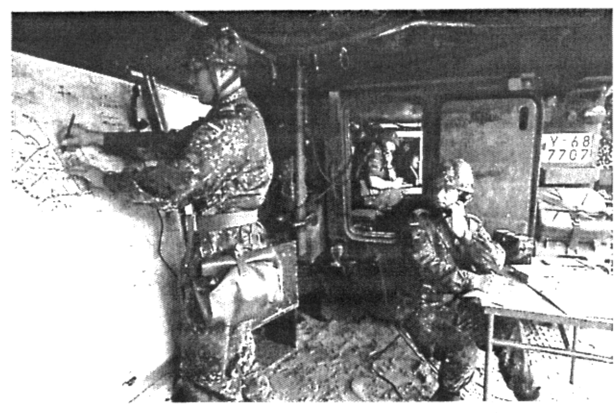

Fig. 2: TSD at command posts "in the field"

On the other hand there are *TSDs at operation centers*, as can be seen in Fig. 3. Tactical situation data is preprocessed and computers are used to visualize the results.

The advantages of these advanced TSD's are:

- actuality of data, provided that the communication infrastructure is fast enough,
- different views of levels of data aggregation and
- possibilities to include additional battlespace information.

But this flood of information may lead to an information overload; moreover data representation is still limited to two dimensions and techniques of interaction with data have to be learnt.

Fig. 3: TSD at operation centers

The approach of using VE as TSD first expands the two-dimensional visualization to three dimensions. This means that height information can easily be perceived. Additional elevation aids, like elevation profiles or color texturing, can be skipped and replaced by others (e.g. reconnaissance photos, weather data, etc.

The more important thing is that general interaction with data is simplified and happens more intuitively. This facilitates an experience of the tactical situation and the generation of a correct mental model. In an ideal VE-system the computer is not realized as an active entity, but becomes an invisible assistant which knows about user intentions and supports him (Alexander et al., 1997). Therefore operator workload is supposed to be reduced and situational awareness to be increased.

4 Approaches of VE-Technology in C²

The amount of studies and applications in the area of VE and VE-technology has increased rapidly recently. But whereas VE is close to become applicable in research and development and for single training applications, studies considering the specific use of VE in C² have just begun. Therefore knowledge in this area is limited and a lot of projects are in a conceptual phase.

Most research studies and projects in this area have been started in the past two years. Because of ongoing development in this area this is only a brief overview. Detailed information is given in Alexander et al. (1999).

Generally speaking, the approaches can be divided into two groups. The first group consists of concepts and long-term programs including VE-components. This is a top-down approach which takes place at high political level and typically application-oriented. The second group is characterized by specific VE-projects and laboratories. Consequently it follows a bottom-up approach and is presentation- and technology-oriented. Fortunately, there are links between both so that they meet and synergetic effects exist.

The Swedish *ROLF (Mobile Joint Command and Control System 2010)* is a long-term program. Its goal is to determine new possibilities for military commanders of using VE-Technology in mobile command posts. ROLF describes requirements for situational awareness, decision making and support, work methodology and organization of military crew and staff. The main idea is to use modern methods and technology to help a group of operators in difficult situations with complex, time-critical decision making. ROLF includes the *Aquarium* as TSD which is a semi-immersive VE-system. The TSD is used to visualize positions of own and enemy troops, positions of important institutions, terrain and weather data in different views. Data preprocessing is used to select the data displayed and ensures that only important information is visible (Sundin, 1996).

Especially the realization that in future battle scenarios all actions of the military commander will be in an unclear, vague environment and the importance of an information dominance led to the development of the *Command Post of the Future Program (CPoF)* of DARPA (1998). The program's goal is to accelerate the decision making process with ongoing reduction of the staff. Therefore new technology is needed to make maximum use of the whole human perceptory system in order to transmit maximum amount of information. This includes an interactive, three-dimensional visualization, three-dimensional interaction with computer-generated objects, presentation of inaccuracy and probability, integration of dynamic factors, three-dimensional symbolic, integration of natural language processing and integration of knowledge-based systems.

The second, more technology-oriented group of approaches is larger. Institutions and laboratories working in this area use different VE-technology. The technology is often reconfigured to be used for different research projects and experiments.

The *US Battle Command Battle Lab (BCBL)* performs conceptional studies as well as experimental analyses in a VR-laboratory. One goal is to develop a technology for a multi-media, scene-based application in education and training for organization and staff functions. This system shall be connected to the internet to increase the range of application (Heredia, 1999).

At the *US Naval Research Laboratory (NRL)* an advanced battle planing and management system has been developed. The system works with a semi-immersive display and enables multi-modal interaction. It was found to be very suitable for virtual-prototyping, interactive mission planing and increasing situational awareness (NRL, 1997).

Similar approaches, like *Mirage* of the Army Research Lab (ARL) (IST, 1997), the *Visualization Architechture Technology (VAT)* of the Crewstation Technology Laboratory (CTS) (Achille, 1998) or the *Electronic Sand Table* of MITRE Corp. (MITRE, 1998) also use a semi-immersive VE-technology, as described further on.

Other approaches use full-immersive VE or desktop-VE respectively (Dockery & Hill, 1996; Morgenthaler et al, 1998).

5 The Electronic Sandtable (ELSA)

The Electronic Sandtable has been developed as an advanced display for tactical information in mission planing, control and rehearsal. The concept is based on the sandtable metaphor. The military sandtable, as shown in Fig. 4, consists of a sandy model landscape with simplified objects representing woods, buildings, points of interest or military units. It is broadly used in military education and training.

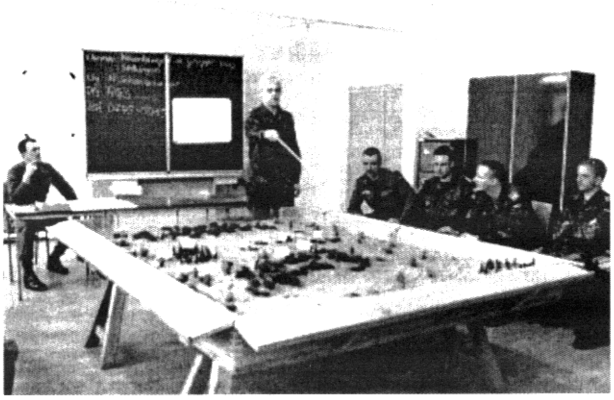

Fig. 4: Sandtable in military education

But the traditional sandtable is static; all changes of deployment have to be done manually. Each change of region is very time-consuming and has also to be done manually. Moreover the accuracy for representing real geographic data is poor.

It is intended to model the sandtable by means of a VE-system. This way dynamics, real-time interaction and changes of the point-of-view can be included while the benefits of the real sandtable remain.

For this purpose geographic data and tactic data have to be visualized stereoscopically. It is intended to create a model landscape, in which dynamic battle scenario is included. Furthermore additional functionality is added, e.g. visibility, range of weapon systems, etc.

5.1 Structure and Technical Implementation

The Electronic Sandtable has been implemented as a testbed at the Research Institute for Communication, Information Processing and Ergonomics (FKIE). A draft of the technical setup is shown in Fig. 4.

Because of the large size of geographic databanks and the need for real-time interaction, the underlying structure has been arranged in two stages (Alexander et al, 1997).

The first stage is executed offline. In this stage the scene graph is determined. The scene graph is a hierarchically ordered databank of all polygons included in the visible scene.

Originally all data is separated in different databanks, which means:

- digital terrain elevation data (DTED),
- digital feature analyses data (DFAD),
- textures (e.g. reconnaissance pictures),
- single geometric objects (buildings, tanks, airplanes) and their attributes.

In a semi-automatic process data and objects are selected, integrated and re-ordered with respect to maximum rendering performance. This databank is called the scene graph. Afterwards the structure of the scene graph stays constant without any changes.

In the second stage additional data is constantly added and the scene graph is visualized online. The additional data, i.e. tactical situation data and data from external

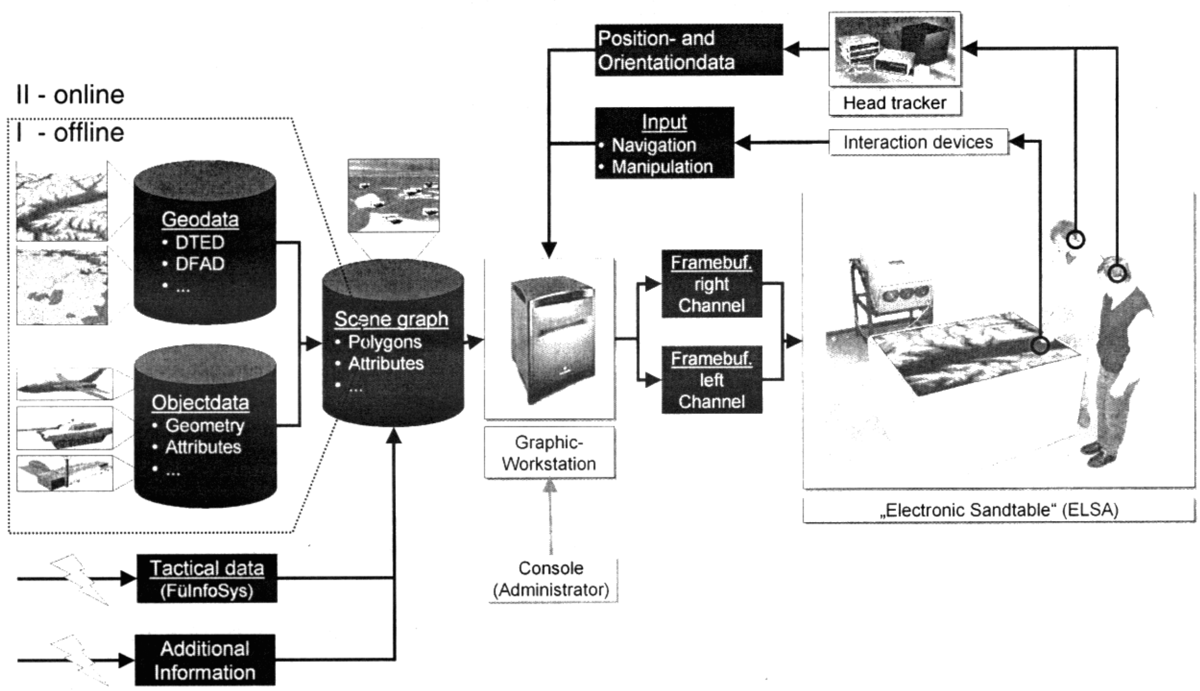

Fig. 4: Structure of the Electronic Sandtable (ELSA)

data sources, is linked to objects of the scene graph. Additional input of external data using different protocols (DIS, HLA) shall also become possible in future. The incoming data controls position and status of military units. Additional data, like actual situation videos or information of knowledge databanks, can also be included.

After that the rendering subsystem selects the visible subset of the scene graph. Out of this two separate projections are calculated and written into the two frame buffers. Then both frame buffers are visualized alternately on a horizontal plane.

The human operator interacts with the scene by means of different interaction devices. The inputs serve as commands which affect the objects of the scene graph. The actions are logged for later analysis.

The operator is able to select different visible areas for navigation. The borders of the area serve as one input variable of the rendering subsystem. Additionally each of the operator's movements is tracked by a head-tracker. The position output of the tracker is another input variable of the rendering subsystem for new projection calculation.

5.2 Generation of the Scene Graph

The scene graph is the output of the first stage described in chapter 5.1. The generation process itself is offline and semi-automatic. As far as possible COTS-products are used.

The process is divided into a data selection, preprocessing and optimizing phase.

Preprocessing and optimizing are necessary because terrain and feature data are generated from geographic databanks. These databanks were designed with regard to different requirements which makes them unsuitable for a real-time, realistic visualization.

5.2.1 Data Selection

In the first step an area of interest is selected and the relating terrain (DTED) and feature (DFAD) data is extracted. Additionally, links between features and geometric objects are defined. Afterwards the selected data is saved in a temporary buffer which has to be preprocessed and optimized for visualization.

The *geographic data* available is divided into (Helmuth, 1996):

- *Raster data:* pixel data (e.g. scanned paper maps),
- *Picture data:* geo-referenced or non-referenced aerial or satellite photos.
- *Vector data:* surfaces (e.g. woods, lakes), lines (e.g. streets, rivers) or points (e.g. power poles, points of interests, bridges, towers) with the position of their bases and attributes. For visualization vector data is linked to detail objects.
- *Matrix data:* data in matrix format of a specific resolution. Usually, terrain data is organized like this.

Geometric objects are components which are linked to geographic data, especially geographic vector data, and tactical situation data. They include a geometric description of the object (e.g. tanks, airplane) and additional information (e.g. unit status, damage reports, etc.). At the stage of real-time visualization they are shown at the position given either by the geographic data or the tactical situation data. General geometric objects are often automatically constructed. However, more sophisticated models have to be designed manually either by a CAD-program, a modeling software or out of an object databank.

For later selection operations *attributes* have to be added. Attributes can be divided into geometric and general attributes. While geometric attributes (length, width, height) are the same for each object, general attributes are dependent on the kind of application. Such attributes might be population data (sociology), pollutant emission (environment) or tactical information (military).

5.2.2 Data Preprocessing

Consistency and integrity are highly important criteria for databanks. If datasets of more than one databank are merged, contradicting data might emerge and cause errors. Those errors are based on errors or inaccuracies in the original databanks, different data resolution or different actuality of data acquisition.

As soon as consistency and integrity is proved, the process of merging terrain and feature data starts. Geometric objects are appended and, if necessary, adjusted to ground level.

Finally the triangulation process starts and determines polygons for visualization.

5.2.3 Data Optimizing

For real-time visualization the amount of rendered polygons has to be minimal. Therefore the databank system transfers only information about the visual subset. Non-visible parts outside the field of view are clipped.

For further reduction the databank is re-organized and the scene graph is tiled. In the visualization process the distance to the point of view sets the level of complexity for each tile.

Different levels of complexity, also called levels of detail (LOD), are another technique to reduce polygons. LOD means more than one representation of different levels of complexity (different amount of polygons) for the same subset. This means, if a subset gets closer to the point of view, a higher LOD with more polygons is visualized.

Using these techniques data is re-organized with regard to visualization issues. The output of this process is the scene graph which is visualized in real-time in the second stage.

5.3 Display Technology

The display technology used for three-dimensional visualization is a semi-immersive virtual workbench. This concept has originally been developed by Krüger & Fröhlich (1992). The baseline concept is shown in Fig. 5. Today it is used for various applications.

A projector projects two computer-generated, time-alternated pictures onto a mirror. The mirror reflects them to a horizontal focussing screen. By using shutter glasses, i.e. LCD-glasses shading each side alternately synchronous to the projection, the operators perceive two separate pictures for the right and the left eye. The synchronization works by an emitter sending infrared signals synchronously to the picture projected.

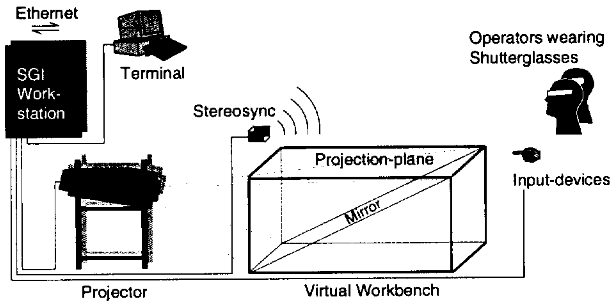

Fig. 5: Principle of a semi-immersive virtual workbench

Finally, both pictures perceived are fusioned by the cerebrum to a single, three-dimensional model.

6 User Interface

The design of the user interface of VE-systems has been found to be one of the main criteria of quality for its application. The Electronic Sandtable serves as the interface between the real environment on the one hand and the virtual scene on the other hand. Moreover it uses a different metaphor than the desktop-metaphor used in various computer applications. Therefore new interaction techniques and procedures have to be developed, analyzed and optimized according to a high performance of the human-computer-system (Alexander, 1999).

This includes visualization, interaction and cooperation in a virtual scene.

6.1 Visualization

A realistic, three-dimensional visualization of terrain data has to consider the physiological procedures of visual depth perceiving. These procedures have been studied extensively, and several different hypothesis for depth perceiving exist.

Each hypothesis postulates the existence of depth cues. The classic depth cues will be summarized later in this chapter. Especially the depth cues of stereoscopic disparity and parallax are of critical importance for the application of the Electronic Sandtable.

A computer-based visualization has to take into account different depth cues. For stereoscopic visualization different viewing models exist. The common models will be presented in this chapter as well.

6.1.1 Visual Perception

The physiological visual system consists of the eye as sense organ for stimulus acquisition, the optic nerve for stimulus transfer and the optic center of the cerebrum for stimulus processing.

According to Schmidt & Thews (1995) the human eye can be divided into two subsystems:

- Subsystem 1 is responsible for the refraction of incoming light. Its main components are: Iris (control of incoming light intensity), lens (refraction), vitreous body (stability) and diverse muscles (adjustment).
- Subsystem 2, jointly with the central nervous system, transfers the light to stimulus signals of nerve cells. It consists of the retina with its two different light receptors.

The stimuli are transferred via the optic nerve to the optic centers of the cerebrum. Here the optic sensing and recognition takes place.

Visual perception is generally based on three stages of perception (Kelle, 1994):

The first stage is an egocentric perception of the own person. This allows a separation of objects of the own body and other objects, making possible to determine the own position with regard to other objects and an *absolute depth perception.*

The next step is a comparision of the objects in the environment, allowing a *relative depth perception.*

Finally memory, experience and internal processing mechanism lead to *depth cues* being fundamental for spatial perception.

6.1.2 Depth Cues

Depth cues are visual system cues which enable perceiving of spatial dependencies (Hodges, 1992; Schmidt & Thews, 1995). The can be divided into monocular and binocular cues.

Monocular cues are valid for perception with one eye only.

The main monocular cues are:

- perspective,
- difference in size,
- known dimensions of objects,
- shading,
- light and shadow,
- accommodation.

The binocular depth cues require the total binocular eye system. They influence the perception of short to medium distances.

Traditional binocular depth cues are:

- convergence:,
- disparity and parallax.

Additionally to these static cues there are dynamic cues which have large influences on the depth perception for medium distances (17 –29 m) (Kelle, 1994).

6.1.3 Disparity and Parallax

Disparity and parallax have a large influence on depth perception and are the main depth cues for stereoscopic visualization. Therefore they are described more detailed.

The distance between both eyes leads to different representations of an object on the retina of the right and the left eye. Both eyes perceive the object with a different perspective. The difference between both pictures is described by the disparity.

If an object is focussed, it is represented at the fovea of both eyes. A round spatial surface exists (horopter), representing all objects on it on corresponding retina areals. Objects at positions different from the horopter are represented at non-corresponding retina areas. If the distance from the horopter is not too large, the cerebrum fusions the right and left picture to a three dimensional model. If it is too large, disturbing double pictures are perceived (Schmidt & Thews, 1995).

Disparity is a mathematical dimension and cannot be determined practically. Therefore the dimension of the *stereoscopic parallax* has been introduced. For this a reference level has been used which is parallel to the eyes' level and runs through the fixation point.

Parallax has been defined as (Helmholtz, 1910, ref. in: Kelle, 1994):

$$p = b_a \times a \times \frac{t}{e * t + e^2}$$

p = parallax
b_a = inter ocular distance
a = distance eyes / reference level
e = distance reference level / object
t = distance eyes / object (=a+e)

Parallax is also a dimension for depth separation and depth perception. Therefore it is deduced that depth perception decreases with square distance. Furthermore it increases linearly with inter ocular distance.

According to Kelle (1994), stereoscopic disparity and parallax has been found to be useful only for near and medium distance (maximum of 6-9 m).

Visualization of geographic data of large scale means a large distance between eye point and surface. It can be concluded that exact modeling means that parallax and stereoscopic depth perception will be very low. Instead inter ocular distance has to be modified to several meters evoking a higher stereoscopic depth perception.

6.1.4 Stereoscopic Projection Models

For three-dimensional stereoscopic visualization three different projection models are commonly used. Their baseline geometry is illustrated in Fig. 6.

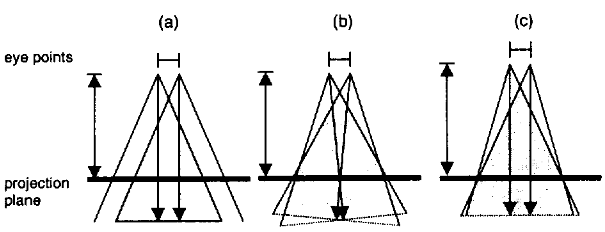

Fig. 6: 3 projection models: (a) parallel projection, (b) rotated projection, (c) window projection

In Computer Aided Design (CAD), aerial photo analysis and for head-mounted-displays (HMD) *projection models with parallel line of sights* are used, as shown in Fig. 6 (a). They are based on the assumption of a center eye-point perpendicular to the projection plane. Right and left projection are calculated by using offset values and parallel shifting the projection right and left. The disadvantage of this model is that the scene can only be visualized underneath the projection plane. This is inconvenient for the concept of the Electronic Sandtable, because the scene would always be located beyond hand range. Another disadvantage is clipping at the borders of the display as there are missing visual information for either the right or the left eye. Especially at large displays this is very irritating for operators.

Fig. 6 (b) shows the geometry of a *projection model using rotated line-of-sights*. Here the projections are rotated in the way that both lines-of-sight meet in the projection plane. The lines-of-sight are not perpendicular to the projection plane. The concept remains the same, no matter if the scene, the eye points or both are rotated. It enables a visualization underneath and as well as above the projection plane. There are no irritating effects on the borders of the display either. But because of the special geometry, an error of vertical parallax appears. This can be observed especially at the borders of the display, where both lines meet at a point above the projection plane. This leads to a "winding"-effect and the scene seems to be projected on a cylinder rather than a plane. The error is perceived especially on large displays.

The last projection model uses *window projection*, which means that two windows are introduced through which the virtual scene is perceived. The windows are positioned in the same level as the projection plane. Both lines-of-sight meet at the projection plane and remain perpendicular to it. This is correct for the middle and the border of the projection area. In this model, stereoscopic parallax is only dependent on the distance to the display and no vertical parallax is introduced.

This model is used for the Electronic Sandtable. As shown in Fig. 7, the model for each eye is described by an asymmetric pyramid. This means, the perpendicular line through the top does not meet the center of the pyramid basis.

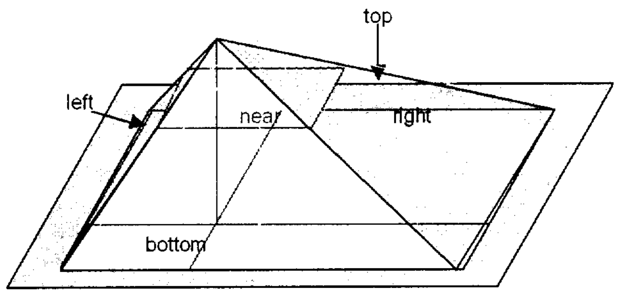

Fig. 7: Right and left asymmetric projection pyramid and boundary surfaces (clipping planes)

For each projection six parameters are used to identify the pyramid. They include the values for front, back, top, bottom, left and right clipping plane. These values are calculated by x,y,z-position of both eye-points, scale factor and the display size as input.

Pilot experiments have shown good results for this projection model. Only little perspective error due to tracking of the real eye position was determined. In future, this error will be minimized by calibrating the tracking equipment.

6.1.5 Future Research in Visualization

So far only real-size shapes have been visualized. In future geographic data of different scales will be used. To evoke a stereoscopic depth perception, an adaption of the scale factor for elevation as well as the dimension of inter ocular distance is necessary.

However, the adaption may lead to either too flat or too heigth depth perception. Both is not wanted and therefore research studies will be done concerning the correct determination of both parameter.

Another research topic is the maximum vertical range of the display. The display technique causes contradicting depth information, because both eyes accomodate on the projection plane, but fixate an object closer or more far away. However, if the virtual scene is too close, parallax becomes too large and the cerebrum cannot fusion both pictures. Therefore another research topic will be to determine the maximum useful vertical display range and the variability of human sense perceiving.

Pilot experiments in this area have been started and are currently going on.

6.2 Interaction

Interaction with the databank means navigation in the scene and manipulation of virtual objects. For both subgroups procedures (software) and interaction devices (hardware) have to be designed, evaluated and analyzed according to the application.

6.2.1 Navigation

Navigation can be divided into: Navigation within the databank system and navigation within space.

The first, *navigation within the databank system,* encloses different procedures for search and selection of datasets. This is a general topic and is not of special interest for VE systems. Therefore it will not be described in this paper.

Navigation within space means a change of position or orientation of the observer. This is, generally speaking, a modification of display area. A first implementation sets a starting position and orientation for the observer. Both can be modified by user input. There are many possibilities for designing the navigation procedure of the graphic user interface (GUI).

One is an adaption of the procedures used by MS Windows© or OS Motif©. An example of this can be seen in Fig. 8. In this concept, the operator has to turn dials or move sliderbars at the sides of a software-window to modify the display area. For desktop computers this concept is familiar, often used and nearly standard. However, on large displays it was found to be very inconvenient. The reason for this is that reaching for the navigation control means to move a cursor a long way across the display and this takes a lot of time.

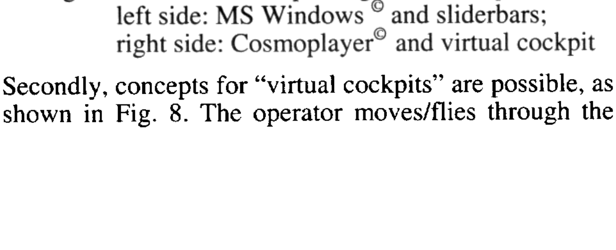

Fig. 8: Different desktop navigation concepts.
left side: MS Windows © and sliderbars;
right side: Cosmoplayer© and virtual cockpit

Secondly, concepts for "virtual cockpits" are possible, as shown in Fig. 8. The operator moves/flies through the scene by controlling a throttle and a virtual control stick shown in the lower middle of the GUI. This technique is often used for desktop-VE systems, especially for VRML-applications. However, for larger displays and semi-immersive VE-systems it has been found to be not efficient enough.

For reasonable use of the benefits of VE, the interaction has to be more intuitively. The concept of *"grab-and-move"* describes a first step in this direction. In this concept the operator grabs the scene and slides it to any direction. First trials using an implementation of this concept show that navigation becomes rather easy and fast.

In the actual experimental setup a trackball is used as main interaction device. Missing degrees of freedom are simulated by additional switches on the device. For future studies evaluations of other devices are planned. One of those will be a virtual laser pointer which makes pointing, selection and navigation possible.

6.2.2 Manipulation

Manipulating the objects of the virtual environment will use the same devices as for navigation. A switch or control bar is used to toggle between navigation and manipulation mode. In manipulation mode the operator has to be able to select objects and choose special control operations.

Main control operations are:

- generation of new objects,
- editing attribute values,
- erasing,
- placement,
- orientation,
- movement,
- editing terrain data.

Generation, editing and erasing of objects can easily be implemented. But placement, orientation, movement and editing of terrain data are more difficult, because interactions between different objects of the scene graph have to be considered. This can easily lead to errors in the structure of the scene graph.

For correct *placement and orientation* of objects in the three-dimensional space elevation information about the base point is necessary. Moreover, if the object is placed on oblique terrain, it has to be oriented correctly. This information can only be derived from the original geographic databank which is not a part of the scene graph. For this reason data exchange with the original geographic databank has to be possible.

Movement of objects is even more critical. It describes the process of detaching the object out of the scene graph and re-placing it at another position. A trivial implementation would be to erase the old object and generate an identical new object at the new place. But intelligent movement algorithms should enable a movement of the object while simultaneously fixating it on the ground level (*terrain following*).

More complex edit operations of the terrain databank are very difficult, because the original geographic databank has to be modified, stored and re-converted into a new scene graph. As said before, this has to happen offline.

Consequently the actual setup of the Electronic Sandtable does not support these operations.

6.3 Cooperation

The concept of the Electronic Sandtable has been designed to enable multiple operator working in the virtual scene. It has to include cooperation concepts.

In contrast to full-immersive VE, in semi-immersive VE all operators are present at the same location. Communication and inter-operator interaction happens the natural way. Therefore mainly human-computer interaction issues have to be analyzed. These main issues and problems will be discussed in the following.

A correct perspective visualization of the computer-generated picture is limited to only one single operator due to technical reasons. The technically possible frame rate is limited to a maximum of 144 Hz. For stereoscopic visualization the rate is cut into halves (72 Hz). An additional operator would mean to cut it into halves again (36 Hz), making flickering as well as occurring of hazardous separation of single pictures likely to appear. In a word it can be summarized that with today's technology only calculation and stereoscopic presentation for a single operator is possible. Further operators will perceive a perspective error.

One way of dealing with the problem would be to track more than one operator and to calculate an average position. Average position does not necessary mean the arithmetic mean, it could be a more complex formula determined by subjective ratings. This way the perspective error might be minimized and might not be subjectively perceivable.

Apart from visualization, cooperation also has effects on interaction and manipulation. For different operators working in a virtual scene, two main concepts exist. The concepts are drafted in Fig. 9.

The *conference concept* is characterized by an active presenter and passive participants. The presenter is able to navigate and manipulate, whereas the participants are following the presentation. There is no real cooperation taking place.

On the other hand, in the *workshop concept*, all participants become active. However, they are given different rights for access. At the beginning of each session, an operational area is set as working region. Afterwards participants are able to work in this region. This concept is not limited to human-computer interaction but has to include cooperation procedures between session participants as well.

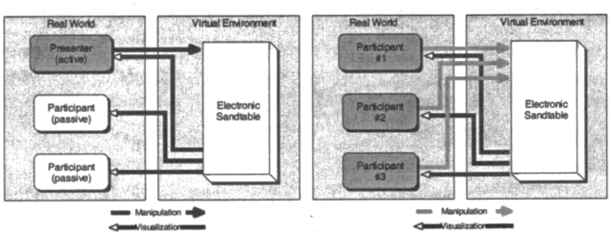

Fig. 9: Conference (left) and workshop (right) concept

A typical example is handing over an object. Participant #1 selects an object and gets access rights for it. For exact placement he hands it over to participant #2. Access rights move over to participant #2 as well. Finally participant #2 drops the object and loses access.

These concepts require the introduction of new procedures and an intense research in this area. Because reality is still to be modeled natural procedures serve as input for the model. But just modeling reality does not consider that VE-systems have much more capabilities. Therefore new advanced concepts have to be formulated, to optimize use and gain benefits of the system.

7 Conclusion and Future Research

In this paper the baseline concept of using semi-immersive VE-technology as advanced TSD has been described. The approach has been shown to be promising and advantageous.

It has been emphasized that human factors and ergonomics are the main issues for reasonable VE-application. Main research issues were found to be visualization, interaction and cooperation. But these topics cannot be analyzed separately, because interactions between them exist. In this paper some research issues were introduced and results of ongoing research studies in the area of visualization were presented.

But even if in future the system works as it is supposed to be, one question to be answered still remains: The question for quantification of the profit and gain of using VE-systems. The key criteria for answering this question will be performance of the human-VE system.

For this reason human performance metrics will have to be introduced, formulated and analyzed. They should be as fundamental as possible, but still take into account the characteristics of the application.

Jointly with other basic research studies they will be the key issues of future research in this area.

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Visualising the Battlefield with Panoramic Displays

Dr H. J. Dudfield, C. M. Macklin and R. P. Fearnley
Probert Building
Defence Evaluation and Research Agency
Farnborough
Hants GU14 0LX
United Kingdom

Summary: This paper outlines ongoing research into the application of shared large screen displays (LSDs) for visualising the battlespace. This research was funded by the MOD's Corporate Research Programme 1999-2000 (TG5: Human Sciences and Synthetic Environments). Completeness and accuracy of information has the potential to enhance awareness of the situation and increases the probability of better decision making by the command team. Thus LSDs may lead to enhanced team situation awareness, and it is proposed that this in turn should lead to more effective decision making. The paper discusses panoramic displays in relation to the potential benefits that would arise when military command teams use them. Understanding of the command team's information requirements is crucial to the operational advantage gained with LSDs. This paper also reports the outcome of a user requirements capture exercise, where users were required to consider their potential information display requirements for an LSD to be used in 2010.

1 Introduction

The panoramic display is essentially a shared visual environment (with a display area of larger than 10 square feet) providing the operational teams with information on the status of assets. Applications of such displays can be as diverse as operational pictures presented to battlefield commanders, to trainers viewing trainees in multi-ship synthetic environments.

Large screen displays (LSDs) as a concept are not new. In the Second World War RAF controllers viewed a large desktop display of the air picture. There are also civil applications in safety critical environments such as nuclear power stations. However, recent advances in computing power have enabled digitisation of many aspects of the military environment. These include higher level requirements such as the presentation of the joint operational picture and specific vehicle-based concepts providing battlefield situational awareness and command. Nonetheless, the development of technology for large screen displays leaves the questions begging as to where the real military benefits are to be gained? In particular, in team environments, how can the LSD help improve operational decision making? Other important questions remain unanswered: how does the design of the LSD impact on Human Computer Interaction (HCI) and how can this be measured? The issues underlying these questions provided the framework for the project reported here. The objectives of the research are:

- To reach an understanding of the potential performance benefits of LSDs.
- To conduct empirical evaluations to develop optimal HCI techniques and formats for interfacing.
- To understand, at a conceptual level, changes to and benefits of team decision making with shared information space.

1.1 Background

Current and future military operations will depend chiefly on the C4ISR (Command, Control, Communications, Computing, Intelligence, Surveillance and Reconnaissance) framework. The force most likely to prevail in any operation is the one that accumulates intelligence faster and more accurately than its opposition. This involves the collection, dissemination, processing and interpretation of large volumes of information.

The current operational environment has resulted in:

- Equipment and missions becoming more complex.
- Risk of data overload.
- Team decision support.
- Tri-service and multinational missions and introduction of joint structure.

To support missions that are becoming increasingly complex, and thus requiring commanders/operations room personnel to act as

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information assimilators and overseers, information displays are being revolutionised. Further, as the likelihood of future missions being joint and/or multinational has increased, the joint tactical picture is of primary importance to mission controllers. Providing timely, accurate and relevant information means much of it may need to be filtered out to protect a commander from data deluge and facilitate his decision-making process.

Technologies such as liquid crystal displays (LCDs), back projection systems, large plasma displays, roll-up portable displays and 'picture window' flat screens are already being used in service or are in development. These will enable high resolution, integrated information displays to be presented on wide angle, panoramic displays simultaneously to a number of personnel. Moreover, the development of interactive technologies (such as shared virtual environments, smartboards and shared whiteboards) will enable operators to interact directly with the LSD using novel inputs (voice, eye, and touchscreen) over large distances.

Hence distributed command teams will become feasible. HCI issues are pertinent to such capabilities: who has the authority to interact with and change data is fundamental. Potential applications are vast and diverse. The command team could be in airborne command centres, on ships, or unmanned air vehicles (UAV) command stations. Battlefield displays could be presented with data fused information on one single, splayed, panoramic screen, which all individual(s) could view; potentially facilitating shared mental models, situation assessment and decision making. This project focused on an LSD application relevant to the three services and joint operations, that is the presentation of battlefield information to the command team. It is envisaged that this particular use of LSDs will have considerable relevance to current procurements and provide generic guidelines for other applications.

1.2 Guidelines for Panoramic Displays

Little is understood of how LSDs improve operator performance and knowledge of the related human factors issues is minimal. For example, most of the existing HCI research is related to standard individual workstations. There are few recommendations for how interfaces on LSDs should be designed, and how LSDs should be integrated within the user's operational environment and task structure. McLeod [1] recommends that LSDs are potentially suitable to support team working when one or more of the following conditions are met:

- Operators require concurrent use of information/displays
- Operators have shared tasks
- There are non-conflicting task needs
- Operators have common information needs
- Feedback is required to be given to whole teams
- Operator tasks require a common frame of reference (i.e. an indication of where an operator is within the big picture, to supply overall context, and/or help prioritise an individual's operation)
- Operator tasks require high-level summary/overview information.

Further definitions of the HCI requirements for interacting with LSDs are scarce. There are three main categories of human factors design requirements relating to physical properties, information display requirements and workspace requirements that must be met to optimise performance when using LSDs:

- Physical display requirements include full colour capability, sufficient viewing angle, high resolution and uniform light distribution.
- Information display requirements include the need for a lack of clutter on the display and the need for critical information not to be altered or deleted accidentally.
- Workspace requirements mean that panoramic displays should be functionally consistent with the physical room layout and integrated with command post positions and roles. Operators must also be familiar with using LSDs.

Finally, how LSDs are applied to the team environment is critical. Stubler and O'Hara [2] generated several guidelines to be applied to the use of shared LSDs in order to enhance team performance, which were grouped into the following four sets of functions:

- *Provide a status overview*: to support high level decision making and enhance team memory, where operators are performing multiple concurrent tasks.
- *Direct staff to additional information*: by posting critical information to update individuals' knowledge states.
- *Aid co-ordination of team activities*: to facilitate team identity and clearly communicate common tasks, where

multiple tasks and proceduralised performance are present.

- *Support collaboration among team members*: by acting as a focal point for team discussions.

It is thus possible that the use of panoramic displays may enhance team performance in a military Command and Control (C2) environment. This leads to the important issue of how panoramic displays will impact on team processes within the command team. Understanding team processes and models is crucial in understanding and exploiting the effect that panoramic displays may have on team performance and processes in a military command setting.

1.3 Panoramic Displays in the command centre

LSDs have been used for several years in a range of civil command centre applications, such as power industries (nuclear and electricity) and transport systems (rail and air), where monitoring of the status of safety-critical systems is essential. These displays are used mainly in normal operations, but need to support decision making in emergencies. As the information portrayed is often complex, these LSDs enable the overseer to trace an event back to its source. In contrast, the military LSDs will need to maintain rapidly changing, unpredictable and conflicting information with safety still being a concern, but mission success being the overriding factor. It is how LSDs will impact on team performance and team processes (e.g. intra-team communication) in a military environment that is little understood [3].

The use of LSDs is likely to have an affect on the following main aspects of team processes: communications, leadership, situation awareness, shared mental models, decision making, workload management, mission analysis, planning and adaptability, and teamwork.

Recent studies that concentrated on realistic scenarios in a military setting, showed that teams do tend to perform better when working with shared LSDs. For example, Hiniker and Entin found that shared battle graphics presented on a large overhead screen seemed to increase the effectiveness of teams by providing more accurate information concerning a wider overview of the situation. In a subsequent experiment [4], participants reported that understanding crisis situation and communicating knowledge of the situation was easier and better with the use of LSDs.

Hiniker [5] has discussed in depth the use of a Common Operational Picture (COP). The COP is an annotated electronic map of the battlefield, showing the location of own and enemy forces. The COP updates rapidly, allowing commanders to visualise the situation and hypothesise possible courses of action. Wentz [6] reported the use of the COP in Bosnia in 1998. It was found to be useful, but better integration between pictures was felt to be necessary.

Nonetheless despite the expected benefits of LSDs, there are few studies identifying user requirements or describing empirical evidence to support the anticipated benefits. The intention of this paper is to outline the knowledge elicitation phase of this research project that feeds into the prototype battlefield LSD, which is being developed as part of this project.

In parallel with this knowledge elicitation phase a communication analysis of a simulated command team exercise was carried out. This is reported in detail in [7]. As Table 1 illustrates, the most common type of communication was providing situation updates (18.9% of the total number of communications), followed by requests for information (15.3%) and providing information on request (14.7%). It was important that these requirements were met in the design phase.

2 Knowledge elicitation

The objective of this phase of the project was to understand how LSDs could provide decision support from the command team perspective. In order to meet this objective two command teams were selected as potential users of LSD technology and knowledge elicitation techniques were utilised to identify their requirements. This involves:

- Understanding the users' HCI requirements
  - Focus groups with two command teams were conducted to identify command team information needs
- Encapsulating their needs
  - Trials to assess cognitive benefits will follow on from the identification phase assessing command performance.

As a consequence of the increasing emphasis on joint operations, the first end-user team was drawn from Operations Team Staff in the UK Permanent Joint HQ (PJHQ) representing joint operational and strategic crisis management. The second command team represented the single-service viewpoint, in this case staff from the Combat Operations team at the UK Combined Air Operations Centre (CAOC).

In order to identify key applications for LSDs, two methods were utilised with Subject Matter Experts (SMEs). These were cognitive walkthroughs and focus groups. Focus groups are a direct and qualitative research approach, often in the form of an interview conducted by a trained moderator among a small group of experienced respondents in a natural manner [7]. This is all done in order to gain an insight into the group subject, through instilling a relaxed, informal atmosphere that encourages spontaneous comments.

Cognitive walkthrough is a technique based on cognitive theory for evaluating the design of a user interface, it attempts to elicit information on how well the interface supports 'exploratory learning'. Cognitive walkthroughs aim to evaluate four aspects; the user's goal, the accessibility of the correct control, the quality of the match between the control's label and the goal, and the feedback provided after the control is acted on. This method is often used in the early stages of design, before empirical user testing is possible. The method involves several approaches ranging from heavily structured questionnaires to more informal but structured group sessions. Such groups are normally composed of the interface designer and a group of his or her peers. One of the group takes the role of 'scribe' (recording the results) and another takes the role of 'facilitator' (keeping the evaluation moving) [7].

As the aim of the PJHQ and CAOC visits was to capture information on military command teams' concepts of LSDs, capturing these concepts required a flexible method. After considering the qualities of both focus groups and cognitive walkthrough, it was decided that the exercise used for both PJHQ and CAOC would be an informally structured group session. This was aimed at evoking a relaxed atmosphere that would capture both answers to set questions and spontaneous comments [7].

During each exercise, the command teams were asked to identify potential uses of LSDs in 2010 and then were asked to prioritise information that could be displayed to the team. Following on from this understanding of how LSD information could support team situational awareness, the SMEs were asked to design a prototype LSD. Finally, in the case of the single service staff, there was a walkthrough of a possible scenario to confirm the layout and utility of the LSD.

3 Results

3.1 Single service LSD

This exercise was designed to capture operational staff views on how LSDs could support the command team in air combat operations. It was also aimed at identifying how critical information should be displayed to and interfaced with by the team. While it was not the intention to derive particular screen layouts, a default screen layout was identified as part of the group activity (Figure 1).

As a result of these exercises, the following two applications of LSDs were evident: briefing and team situational awareness. In particular, the LSD would benefit staff shift changes and maintain team awareness of events that they were not party to at their own consoles. The commander commented that the LSD made a good focus for team attention during briefings.

Displaying weather information was an important LSD requirement. This was viewed as an important factor for hand-over briefings, predictions and continual reference during operations. As with all the information displayed, it was suggested that such a display should be totally flexible and able to be applied to any situation.

Unlike the joint team exercises, the single service operational team did not view news feeds and video conferencing as essential. The team suggested that the prime information source for the LSD should be exactly what the Chief of Combat Operations (CCO) desires on the screen at any particular time. Interaction should be mainly through the CCO, although others should be able to take over and manipulate the LSD as necessary, e.g. when briefing. It is useful within a scenario for each member of the Operations team to be able to brief in turn, using the LSD where necessary to update all team members' situational awareness. This raised the issue of live bulletin boards. The team suggested that such a concept would prove to be a useful tool. The idea behind a 'bulletin board' would be a common area where any one of the Combat Operations team could project information onto the LSD, thereby attracting the shared attention of the team to important information. In addition it was suggested that the screen should have a 'zoom' function that would allow any relevant information to be selected from the screen and be re-sized as required.

As a final product of the exercise, a default screen layout for an LSD with suggested functionality was proposed (Figure 1). It was felt essential that all windows were moveable and re-sizeable. The interface should be controlled by the CCO (except for the bulletin window). All team members should have access to a remote mouse for giving briefings, enabling them to highlight/manipulate windows of interest. Further, the team should be able to record all actions, so they could review events and save useful configurations for later use.

3.2 Joint LSD

A similar exercise and discussions were conducted with the joint team operating at strategic/operational level. The following summarises user requirements:

- The interface should utilise current computer formats, for example the use of windows, drop down menus and icons.
- All screen formats should be reconfigurable.
- Users should have the ability to move between levels of information at the click of a button; for example view a map at different resolutions.

As the joint operations team controls a number of operations simultaneously, the LSD must have the ability to display the information for a number of operations at the same time. The background of each section of the display was the respective operational picture. Extra information required for the task from a range of sources including video, imagery, newsfeeds, video conferencing, briefings, etc. can also be displayed (see Figure 2).

Furthermore, when required, it may be necessary to promote one of these operational areas to fill the entire LSD with the remaining operations being minimised. It was also important that the LSD reflected the control room layout and operating functions.

In addition to team situational awareness, the LSD would be used to brief important visitors. The joint team was often in the position where they are required to display information centrally. Therefore there is a requirement for the whole screen to become a dedicated briefing facility.

It was clear that from the joint perspective there was a strong user requirement for an LSD and support for a flexible, versatile system.

4 Generic HCI guidelines for LSDs

As a result of the exercises investigating optimal LSD format, involving joint and single service staff, three general categories of recommendations for display design have become clear. These fall under the headings of: display configuration, interaction procedures and user group considerations.

4.1 Display configuration

A large screen display should:

- Be flexible and re-configurable to the needs of different user teams and their composition.
- Have the ability to move, re-size and overlay any information sources onto and over any area of the LSD.
- Have the ability to zoom in or out of any area on the main display.
- Display information at its highest level; plans and workings are not recommended for display (unless the tasks of the team demand it).
- Make the best use of the available space in any section of the display.

4.2 Interaction procedures

- LSDs must be simple and straightforward to operate.
- LSDs must conform to population stereotypes (i.e. user expectations about how the system will work).
- Access to and exit from any LSD systems should be via one procedure (e.g. one click of a mouse button).
- There needs to be a process whereby useful layouts and/or settings can be saved.
- Movement between different levels of information should be at the click of a button.
- The LSD should provide an 'on-line' help procedure.
- The LSD should have a system that runs hand-in-hand with a time-line of significant

events. Therefore providing traceability of all decisions.

4.2 User group considerations

- LSDs must be designed around how the user team works, rather than dictating how the user team works.

- LSDs must support communication. This can be achieved by matching the needs of the team with the information that is displayed on the LSD to support intra-team communication.

- Interaction with the LSD should be primarily through the CCO, however any member of the command team should have the ability to manipulate the LSD for briefing purposes via a single, communal remote mouse.

- It is essential not to design out the role of the individual. LSDs should be used to increase situational awareness for all team members and allow for individuals to carry out individual tasks independently.

- There should be the provision of two types of LSD, a fixed version and a deployable version. The deployable LSD version should be portable, robust and reliable. Both versions should be functionally similar to avoid the need for additional training.

5 Conclusions

The changing nature of world security has dictated the requirement for flexible and deployable forces. Some of the impacts of the security environment and technology progress on military operations have been reductions in crew levels, interest in remote control of systems, e.g. Unmanned Air Vehicles (UAVs), and the need for complex command and control structures. The philosophy of developing an interface that allows team members to develop an accurate mental model of the location, activity and performance of assets may be a key component in minimising the risk of operator error due to an incomplete/incorrect awareness of the operational situation. The introduction of LSDs will have the potential military benefit of allowing the commander and command team to share information space, potentially enhancing situational awareness and team decision making.

Nonetheless, there are many unknowns in assessing the potential operational benefit of LSDs, both in terms of the optimal HCI, and methods to assess team performance benefits. As a result of this research, there is a greater understanding of how operational pictures are currently used and how future LSDs can be designed to optimise command team performance. This report has identified LSD HCI requirements for operational tasks that can be used in future designs.

6 Acknowledgements

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Communication type	Number	Percentage of total communication
Providing situation updates	240	18.9
Requesting information	194	15.3
Providing information on request	186	14.7
Providing information without being asked	104	8.2
Commands/orders	102	8.1
Questions/enquiries	91	7.2
Seeking clarification	74	5.8
Acknowledge/verify/confirm	47	3.7
Observations	40	3.2
Providing assistance/backup	38	3.0
Guidance/suggestions	34	2.7
Providing clarification	32	2.5
Requesting backup/assistance	21	1.7
Repeating information	20	1.6
Stating priorities	17	1.3
Social/other	13	1.0
Giving feedback	5	0.4
Prompts	4	0.3
Error correction	3	0.2
Agreement	2	0.2

Table 1: Communication types in frequency order

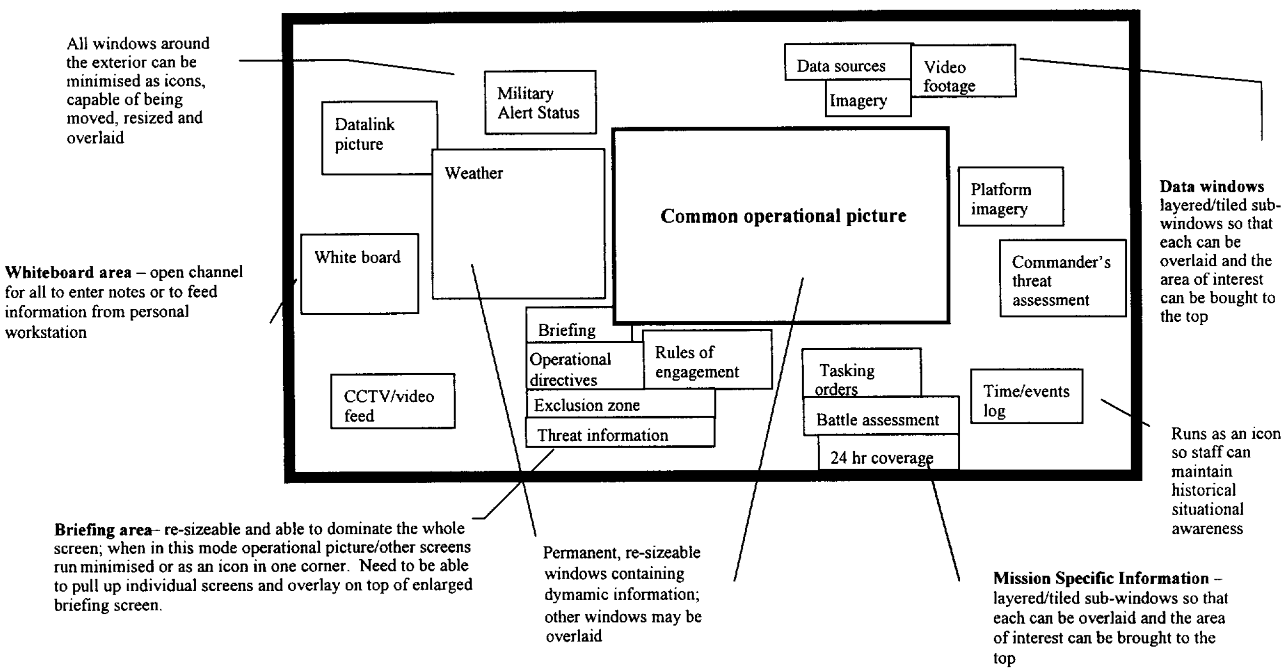
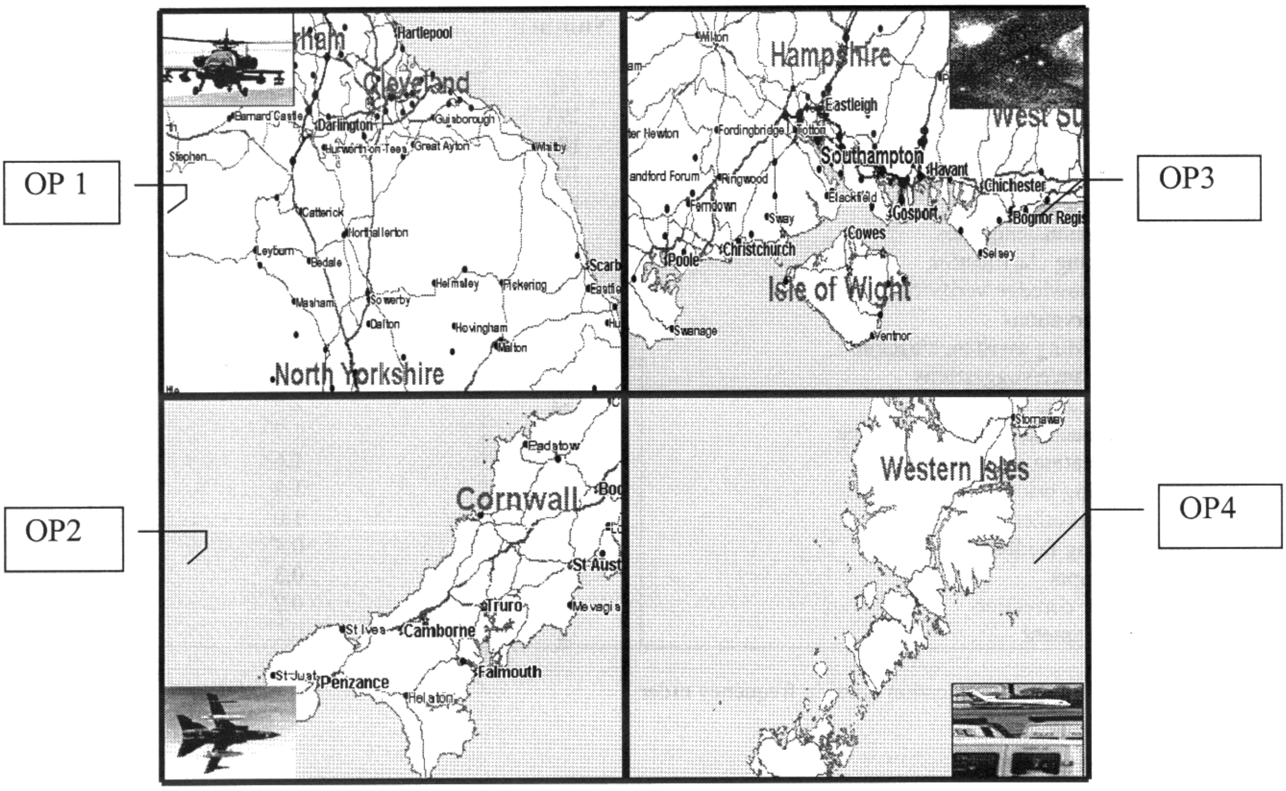


Figure 1: Generic single service LSD layout



*(The operational boxes OP1, 2, 3 & 4 represent which operation each quadrant will be displaying and will not appear on the LSD.)

Figure 2: Joint services LSD screen layout (for four operations).

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Interface Concepts for Command & Control Tasks

Drs. Jan H. van Delft & Dr. Peter O. Passenier
TNO Human Factors Research Institute
P.O. Box 23
3769 ZG Soesterberg
The Netherlands

Summary
This paper addresses new interface concepts for information visualisation and manipulation in Command and Control. These concepts focus on the use of multiple views on the tactical situation to enhance situational awareness and to improve situation assessment. Topics covered include the application of 3D perspective and stereoscopic displays.

INTRODUCTION

With command and control operations becoming increasingly more complex, there is a growing need for research on and development of effective command support tools. Probably due to the strong emphasis on information and technology, but certainly due to shortcomings in our present understanding of command and control tasks, and the human capabilities they call on, many of today's command and control systems are more designed from an information system perspective than from a command support perspective.

To get a better understanding of tasks and needs for support, the analysis of tasks and the identification of critical performance shaping factors in the CIC have been subject of several studies for the RNethN. What can be learned from these studies is the need for better tools to support situational awareness and situation assessment.

Easy access to information needed for these processes of awareness and assessment strongly depends on how the environment, situation, plans and system states are visualised and the way these views can be manipulated. Started as monochrome representations of raw radar and sonar data, the present-day tactical picture has developed into full-colour, computer-generated graphical representations of tracks (figure 1), serving as a basis for the presentation and flexible manipulation of different kinds of tactical and geographical information. Within this scope some new interface concepts for information visualisation and manipulation will be

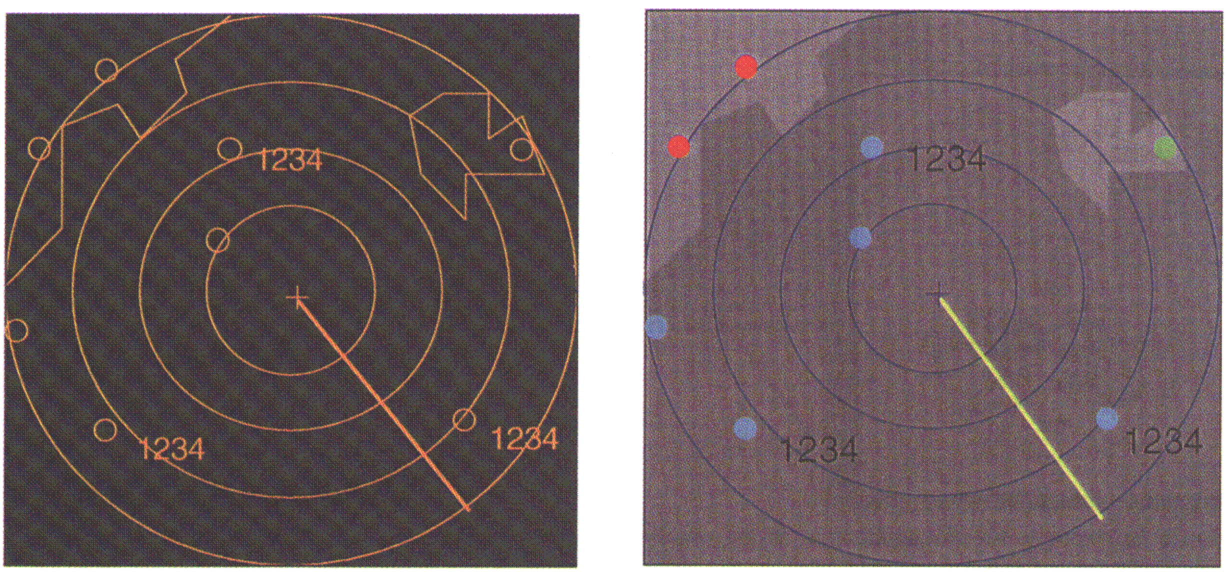

Figure 1: Evolution from monochrome vector display technology to present-day, full-colour raster-scan or flat-panel display technology. As a result of these developments, more possibilities for the presentation and manipulation of tactical data are offered.

Paper presented at the RTO HFM Symposium on "Usability of Information in Battle Management Operations", held in Oslo, Norway, 10-13 April 2000, and published in RTO MP-57.

discussed. These include the use of multiple windows and (a.o. '3D') views on the tactical situation to enhance situation awareness, and the application of transparent information layers for an integrated presentation format. Results of experiments with the concept of multiple views indicate that higher information transfer rates could be obtained, together with a large decrease of required user interaction with the system. Finally, as an extension of the principles described here, the concept of tactical objects is introduced. This concept enables the user to modify and reconfigure the tactical workstation for effective supervision of and a rapid response to the tactical situation at hand.

Although the proposed concepts certainly need further testing and development for successful application, it will be concluded that they offer a promising perspective for the development of future information and task management tools.

MULTIPLE WINDOWS

In current command information systems and combat direction systems, information on the environment is mostly presented in a single, two-dimensional 'bird's-eye view', commonly denoted as the tactical picture. Inherent to this single-view presentation type, is the constant need to zoom in or out and to pan horizontally or vertically to keep the right focus on the tactical situation. Larger scale or longer distance views have to provide the necessary overview, smaller scale or short distance views the detailed information. In many cases it is hard to get both objectives combined in one unique setting of the tactical display. Larger scale or longer range settings often produce clutter or cannot offer information in enough detail. Smaller scale or shorter range settings required for the detail often do not offer enough context for a more global view of the tactical situation, and entail the danger to be 'taken by surprise' where relevant information stays out of sight. Switching between different display settings takes time. Not merely because of operator actions needed, or because of system response times, but above all because of the inevitable re-orientation on what is displayed when settings are changed. A situation in which sudden transitions can cause, as indicated by Woods [1], a loss of visual momentum. As a consequence, when under time pressure, operators may become reluctant to change settings, even if the way information is displayed does not suite the current situation.

Within this scope a study was performed on

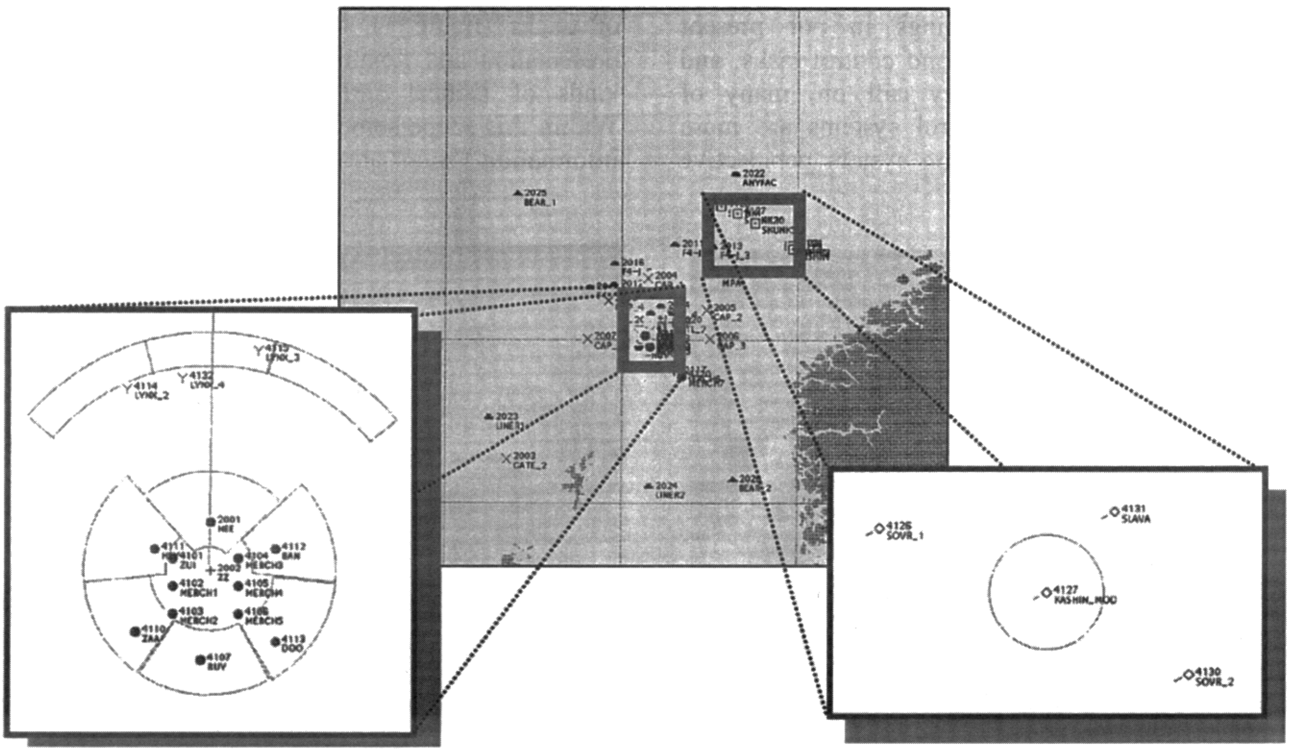

Figure 2: Example for the application of the multiple-window principle with operator selected parts of the tactical picture presented in separate windows for close monitoring. Every window has its own tools for filtering, display settings, positioning and sizing of windows. Separate windows can be temporarily 'closed' through minimising to icons presented on the overview display.

possible techniques to enhance the presentation of tactical situations [2]. The prime research goal for this study was the support of warfare officers in their situation awareness through parallel presentation of multiple windows on the tactical situation at hand, and flexibility in display configurations to support a situation dependent, optimised presentation.
The technique of multiple windows enables the operator to monitor different parts of the tactical environment in a parallel way and at different levels of detail (see figure 2).

In the experimental set-up as tested, operators had a tool at their disposal to select parts of the tactical picture (the overview window) for presentation in separate, additional windows. These windows have their own tools for filtering, display settings, positioning and sizing of windows. The windows can be temporarily 'closed' through minimising to icons presented on the overview display.
It was expected that the use of multiple windows would have a positive effect on the alertness of operators with respect to changes in the environment. To test this expectation, eight warfare officers took part in an experiment in which performance in terms of information transferred and effort needed was measured for both a conventional 'single window' set-up (SW) and an experimental 'multiple window' set-up (MW). Subjects were asked for two different Anti Air Warfare and Anti Submarine Warfare scenarios, while monitoring the tactical situation, to detect and indicate as fast as possible changes in track behaviour, like course and speed, and other state variables.
Changes to be detected in these scenarios could be short-lived, representing the upper part of the transition frequency domain, or more lasting in different degrees, representing the lower part of the transition frequency domain. For the different parts in this frequency domain information transfer was measured in terms of detected changes relative to changes present in the scenario. For the analysis these changes could be weighed according to tactical relevance.
In figure 3 the information transfer function of tactically very relevant transitions ('high-priority targets') is presented for the multiple and the single window interface.
The results show that, given enough time (low transition frequency), nearly all 'high priority' transitions are detected and the information transferred approaches the maximum value of 1. This holds true for both the single and multiple

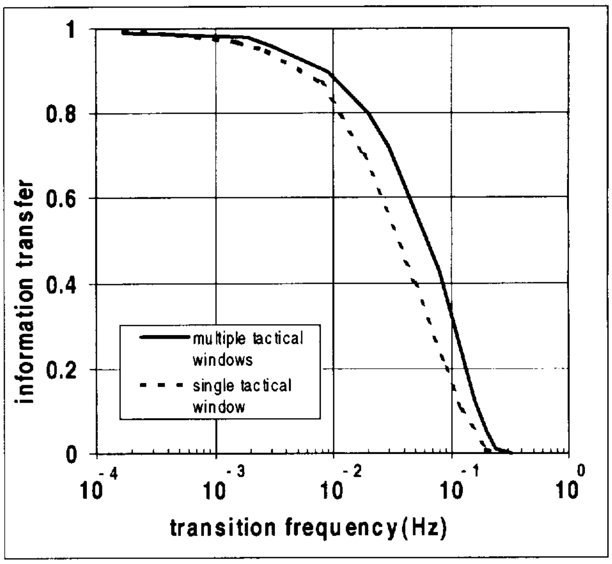

Figure 3: Amount of information transferred to the operator in multiple and single window conditions, as a function of the transition frequency. Low transition frequencies on the left side correspond with longer lasting changes in the tactical situation, high transition frequencies on the right side with short-lived changes.

window set-up's. However, an analysis of variance (ANOVA) on the transient part of the information transfer (transition frequency about 0.1 Hz) showed a significantly higher information transfer for the multiple windows condition, compared to the single window condition. Furthermore, as a measure of effort, all switching actions related to changes in display settings were recorded. The results are represented in figure 4. An ANOVA showed this number to be significantly lower for the multiple-windows condition (150 for the MW condition, 263 for the SW condition). In this experiment no specific effects could be found related to warfare type (AAW en ASW).

Resuming, results of the experiment show that the use of multiple windows has a positive effect on the speed of detection for high-priority targets. Given the frequency with which changes took place in the scenarios, subjects had less time to pay attention to lower priority changes. For these changes it took the subjects much more time to detect them, if detected at all, and as a consequence differences between the single and multiple windows conditions became less pronounced.
As an indication of required effort at the interface level to achieve a certain detection performance, a substantial reduction of user actions is obtained for the multiple windows set-up. Evidently, for the

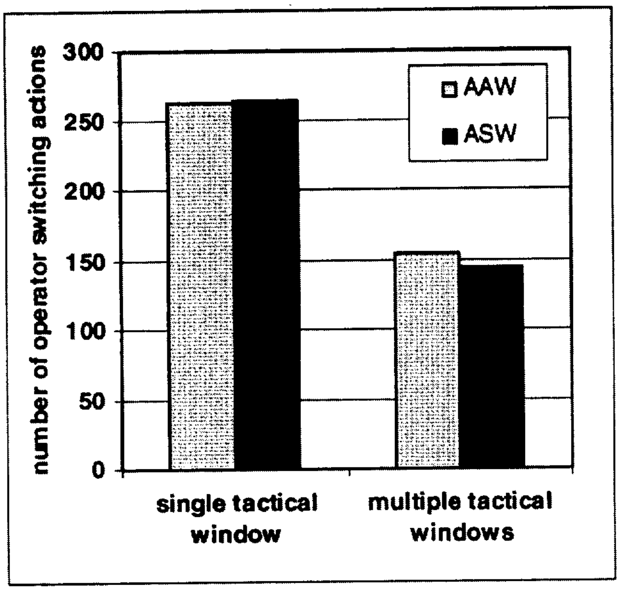

Figure 4: Number of operator actions related to changes in range selection and other display settings for two different scenario types (AAW vs. ASW), tested under single- and multiple-window conditions.

multiple-windows set-up subjects were better supported in tailoring the information presentation to the current tactical situation, resulting in less 'switching' effort required for this tuning process between interface and environment.

MULTIPLE VIEWS

As described in the previous section, information on the environment in current command information systems is presented in a two-dimensional 'bird's-eye view'. Regarded as much more effective than the older generation displays, new advances in graphics capabilities and display technology, however, may offer options for further improvement. In search for further integration, one of these options is certainly the application of 3D perspective or stereoscopic displays.

The strongest motive to go three-dimensional is the inability to combine the two dimensional 'bird's-eye view' with a graphical presentation of altitude and depth information. As a consequence, in all current systems altitude and depth information is presented as numerical read-outs. According to Dennehy et al. [3] representations lacking integrated altitude and attitude information complicate situation assessment in two ways. Data that are difficult to acquire, are more difficult to use in making a decision. Also, without immediately evident altitude information, a decision maker may substitute arbitrary or situation-biased altitudes, that may be difficult to supplant even when the actual data are presented.

With more realistic images of the environment and tracks in a 3D perspective, they argue, the interface becomes more natural and less effort is required to comprehend the current situation. It eliminates the

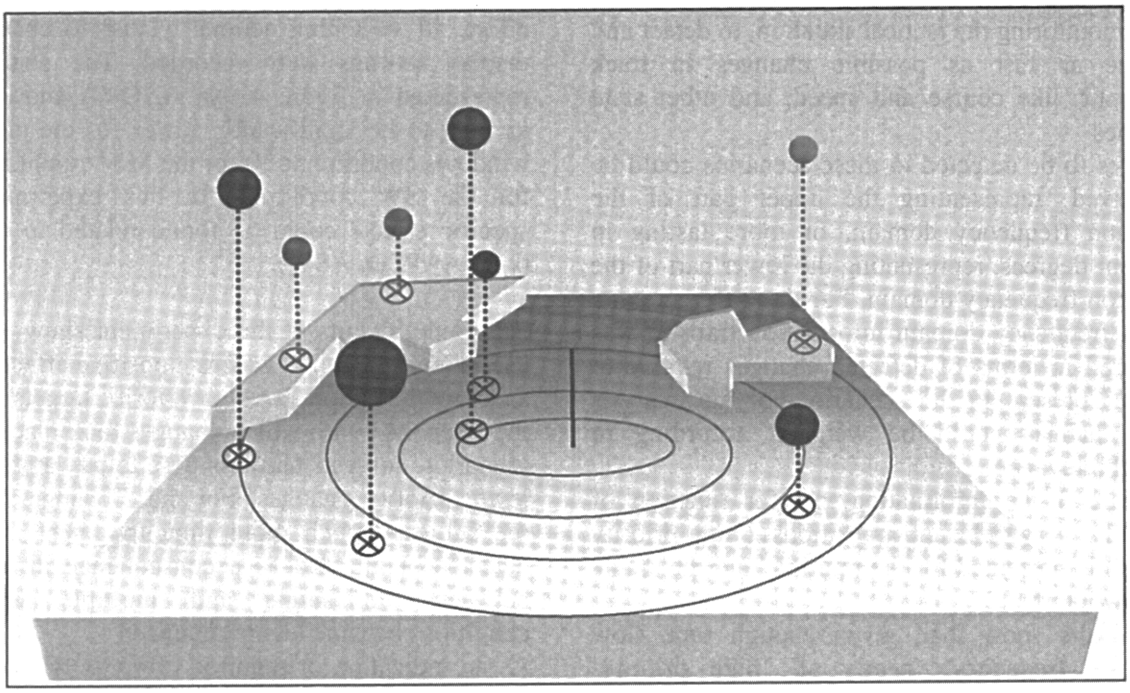

Figure 5: Example of simplified tactical picture presented on a 3D perspective display, with air tracks projected on the surface plane to amplify precise perception of position and altitude.

burden of integrating and interpreting of multiple representations, abstract symbols, and textual read-outs. Some earlier experimental results with perspective displays confirm these expectations. In a direct comparison between a conventional and a perspective display Bemis et al. [4] evaluated operator performance for two different types of tasks: detect threats and select the closest interceptor for each detected threat. The experiment revealed a significant reduction in errors of detection and interception with the use of a perspective display. Also response time for selecting interceptors was greatly reduced. Indicating the potential to improve performance, 3D perspective or stereoscopic displays, however, can also have their drawbacks. Inherent to the perspective view, objects are presented larger or smaller as a function of the operators viewing distance, location and angle. Objects close to the operator will be shown with much more resolution than objects at larger viewing distances. In many cases these differences will not necessarily reflect differences in tactical relevance and meaning.
One can also question how accurate altitude or depth

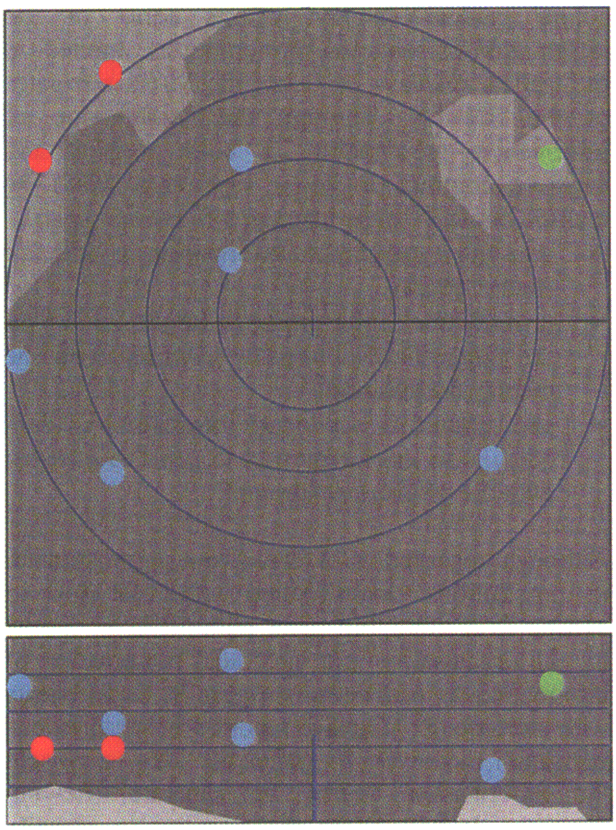

Figure 6: 3D perspective split-up in 2D view from above and side-view, as an example for what is defined as a multiple view display.

information can be perceived. To prevent errors, and to facilitate more precise altitude perception, extra visual cues have to be added like projections on the earth's surface and ruled vertical lines connecting the object symbol and the surface (see figure 5).
Furthermore, to resolve ambiguities and to reduce clutter, operators should have full control of viewing distance, angle and position [5]. Although this will give the operator the flexibility to visualise tactical data more freely it is not clear what effect frequent changes in view will have on orientation and situational awareness.
To study the last question in particular, an experiment was conducted to test how solid or reliable the internal representation of a tactical situation is when the situation has been extensively explored from different viewing locations [6]. Air and surface objects in the explored situation were moved, removed or interchanged position. Some changes were easy to recognise, others more subtle. Shots of the changed situations were put together with shots of the situation as explored, and subjects were asked to judge every shot on whether the situation was changed or not. Performance for a 3D stereoscopic display was compared with a 2D multiple-view display. This 2D multiple view was a composite display, with a side-view added to the conventional bird's-eye view (see figure 6). It lacks the integration of the 3D display, but has the advantage of a graphical representation of altitude or depth, without the drawback of perspective distortions.
Results of the experiment show that performance was not as naturally in favour of an integrated 3D display. Subjects in the 2D multiple-view condition had a significant higher score on correct identified shots, being the tactical situation as explored or a situation that had changed (see figure 7).
Analysis of data from a second experiment, to be reported this year, show, in addition to this result, that differences in sensitivity to changes especially hold true for the small, more subtle changes. Regarding response time, the time needed to identify a tactical situation as unchanged (same) or changed (different), responses for the 2D multiple-view condition had the tendency to be a little bit slower, but the difference was too small to be statistically significant.
Although more experiments are needed with more tasks to be tested, the results put some doubts on explanations that performance improvements as found in earlier experiments largely depend on integration in a 3D perspective display. An even better performance was found with related, but non-integrated multiple views of the tactical situation.

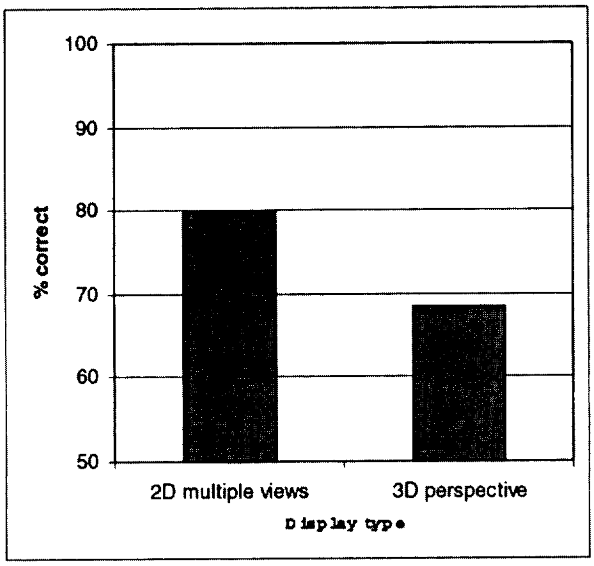

Figure 7: Percentage of correct same-different answers to questions testing the operator's sensitivity to changes in the tactical situation. Scores are presented as deviations from the 50 % baseline, associated with completely random, non-sensitive operator behaviour.

The change from numerical read-outs to the graphical representation of altitude or depth seems to be the most important one to realise a more effective information transfer and an improved situational awareness. With integration no further improvements were obtained. Disadvantages of perspective views even seem to have a suppressing effect on performance accuracy.

MULTIPLE LAYERS

The most obvious application of 3D stereoscopic displays is to get an almost 'natural' representation of objects in the battlespace, as described in the previous paragraph. Stereoscopic vision, however, can also be applied for the visual separation of different information layers with each layer containing two-dimensional representations.

With the transition from vector displays to raster-scan displays and flat-panel displays in the near future, together with fast powerful graphics processing, the potential for all kinds of graphical representations of information has strongly expanded. As a result, many categories of information can be brought together in one integrated graphical representation of the environment and the tactical situation.

To prevent problems like display cluttering or visual interference and to optimise the tactical picture for the task or the situation at hand, new generation systems offer extensive filter and display options. In practice however, operators show reluctance to use the flexibility offered where too many options have a negative impact on overview and accessability, and extensive interaction with the system is required, especially under time pressure.

Another way to cope with this problem is to search for well-balanced visual representations in which the perception of objects like air or surface tracks does not interfere with the perception of supporting graphical information in the background. Some new opportunities to accomplish a better visual seperation between foreground and background information became available with the introduction of full-colour displays.

An example of the difference between the classical monochrome tactical display and a full-colour tactical display was already given in the introduction (figure 1). This example of the full-colour tactical display reflects some of the information-presentation principles as applied to the tactical displays on board the M-class frigates of the RNethN. Through the combination of information presentation in both positive and negative contrast, a visual seperation could be realised between three different information layers:

- area filled geographic information in different shades of gray,
- primary track information in bright colours on the foreground in *negative contrast* with the display background,
- and supporting, secundary information in dark colours on the foreground in *positive contrast* with the display background.

Although regarded as a significant improvement, the possibilities remain limited and do not allow to expand to a more full-scale multiple-layer model for the organisation and integrated presentation of information as presented in figure 8. Experiments with stereoscopic displays reported in the previous paragraph, however, triggered the idea to present the information layers at separate viewing distances. It will allow the operator to visually focus on one layer in the context of information in other layers.

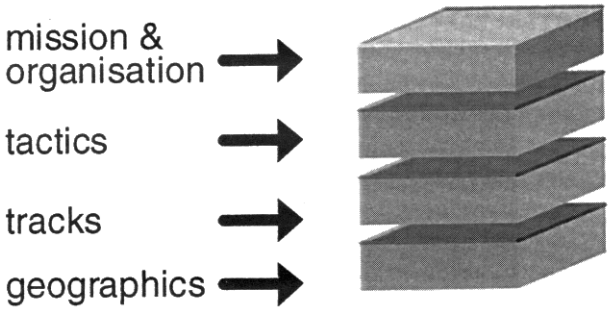

Figure 8: Multiple layer concept for the organisation and integrated presentation of information.

What the impact will be on performance in terms of situational awareness, assessment and decision making is still unknown. Many research questions have to be answered. As part of a research program on emerging interface technologies and their application in command and control, preparations have been started to build a concept demonstrator, to have the tools to test and evaluate the potential of such a tactical display.

TACTICAL OBJECTS

Besides the increasing amount of available information, present-day combat management systems offer a large variety of functions and services, possibly set up in a flexible way for the tuning of this functionality to the different operator roles. However, a possible negative side-effect in this approach may be the rather diverse ways in which the required information for important tasks such as threat evaluation, assignment of sensor/ weapon systems, and weapon deployment, is divided over different system services. Thus, it requires a certain amount of mental effort to maintain overview of the 'flow of information', system settings, filters etc. This problem may be enlarged by the variety of functions and services which are available through various (a.o. soft-key type) input devices, with a lack of context sensitivity.

Within this scope, possibilities for innovation currently are under study, exploring the way in which functions may be represented and organised in future tactical workstations. Based on the 'select then operate' principle, system effectiveness possibly may be increased by considering the tactical display not only to be an output medium for the presentation of tactical data but also an input medium for the selection and activation of functions. The envisioned outcome of this study is an object-oriented interface design, enabling the user by direct manipulation of 'tactical objects' on the tactical display to modify and reconfigure the tactical workstation for an effective supervision of, and rapid response to the tactical situation at hand.

DISCUSSION AND CONCLUSIONS

Within the next generation combat information centre, command teams will have to interact with complex information processing systems. Data from many sources in large databases have to be selected, combined and manipulated. From a warfare officer's point of view, usability and accessibility are keywords of primary importance. Easy access strongly depends on how the environment, situation, plans and system states are visualised, and the way these views can be manipulated. New concepts and technologies for graphic information presentation and object manipulation, both two- and three-dimensional, already are or will become available

In this paper some new concepts have been introduced. The common denominator seems to be the word *multiple*: multiple windows, multiple views and multiple layers. They all reflect the problem of integrating growing information flows in one view or window known as the tactical picture.

Results of experiments indicate how the organisation of information in separate windows, views and layers can improve information transfer and situational awareness.

The way information is organised, however, also depends on the task and the tactical situation at hand. The next challenge is to develop a tool for easy re-organisation of information display when operators have to switch between tasks or when changes in the tactical situation take place. Development and testing of the tactical object as an organising principle is regarded as the first step to meet this challenge.

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INTEGRATING INFORMATION FROM MULTIPLE SOURCES: EXPERT DECISION MAKING PROCEDURES

Dr. Susan S. Kirschenbaum
Naval Undersea Warfare Center Division Newport
1176 Howell St.
Code 2211, Building 1171/1
Newport, RI 02841-1708
USA
kirschenbaumss@csd.npt.nuwc.navy.mil

Summary: Battlespace Management systems are often developed by decomposing the problem into separate functions. For example, the battle scene is decomposed into intelligence reports, sensor displays for each sensor, contact tracks for each sensor contact, environmental (weather, oceanography) conditions and predictions, sensor effectiveness predictions, geophysical / physical oceanographic pictures, etc. Once the problem has been decomposed and analyzed, the decision maker must put it back together in a mental information fusion process, integrating information. The tools to help the expert decision maker re-fuse the problem are far fewer and more difficult to develop than the tools to decompose. The research reported here takes an alternative approach by providing information displays that cluster and integrate information according to the expert decision maker's knowledge schema and procedural structure. A complex, time-dependant (but non-military) test domain with multiple, conflicting goals was selected. Functional partitioning required greater effort while procedurally based information-clustering resulted in more efficient (timely and accurate) decision making.

INTRODUCTION

The Problem: Battlespace Management systems are often developed by partitioning the problem into many functions or tasks. For example, one tool displays all the broadband noise, sensed in all directions. Another provides a similar display of narrowband noise received by each sensor. Another tool makes environmental (atmospheric or oceanographic) predictions for specific variables (wind / current speed, temperature profile, etc.). Yet another tool gives the current conditions. Several algorithms work to solve the target-motion-analysis problem. Thus each unit in the battlespace is decomposed into many separate signals and kinematic components, all independent from one another and from their underlying physical location and the constraints that it imposes. Decomposition facilitates efficient engineering of the algorithms and programs. Each function has its own set of developers, and therefore, its own set of tools. The consequence of this approach is that the problem is split into many different unassociated bits of information. However, the partitioning scheme is not necessarily congruent with the way that the decision maker solves the problems.

The task of the decision maker is to evaluate the available information, predict the effects of various action options, and communicate the decision. Evaluation includes integrating data from the different sources described above, comparing conditions to assumptions, assessing accuracy, etc. The available information is composed partially of the output of various tools and partially of unanalyzed or "raw" data. It includes history, current state, and predictions. It may contain considerable uncertainty and/or may change over time. Required decisions may include both what to do and when to act. Information management tools and decision aids are developed for these tasks because they are so complex and because the supporting information is so complex and uncertain. However, once the problem has been decomposed and analyzed, the decision maker must put it back together in a mental information-fusion process, integrating information from these many tools and phases. The tools to help the expert decision maker to put the problem back together are far fewer and more difficult to develop than the tools to take it apart.

A Proposed Solution: An alternative approach to decision aid development is to start with an understanding of the knowledge and procedures of the expert decision maker and then design tools to support these. With this knowledge, we could design information management decision aids in the way that new walkways are sometimes planned. That is, where natural paths occur because of repeated use by pedestrians, constructed (concrete, macadam, gravel, etc.) pathways are built. In the same way, battlespace management tools and decision aids should provide support for knowledge in the head -- the procedural paths we create through the task and the information.

Experts make use of the procedural components of their knowledge, as well as the declarative content: That is, they know *how-to* as well as *what, why, when,*

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and *where*. Tools used to do a task and procedural knowledge of that task are not independent entities. The tool can facilitate the task procedures or, in the case of clumsy automation (Wiener, 1989), dictate conflicting procedures. The organization of information can provide the cognitive equivalent of affordances (Norman, 1988) or "handles" that facilitate performance or obstacles that hinder it. For example, calculators can use either arithmetic notation or "reverse Polish" notation. Arithmetic notation allows the user to enter numbers and operators as they would on paper (3 + 2 =) and supports the average user's procedural knowledge. Reverse notation requires the user to enter numbers first and then operators (3 2 + =). Although this notation groups like information (numerals, operators) together, it requires the average user to reorder the information from normal arithmetic procedures.

There is a well documented interaction between knowledge in the head and information in the world. Kleinmuntz and Schkade (1993) reviewed several studies that show how problem representation affects the speed and accuracy of identifying and assessing the situation, and consequently, the quality of the decisions made with that information. For example, Johnson, Payne and Bettman (1988) found that display format effects the likelihood of preference reversals (a well-documented decision error) in choice decision making. Decision makers in these studies shifted information gathering strategies as a function of display format. Brown and Klayman (1989) and Smith (1989) found that representation affects subjects' ability to identify key problem elements in naturalistic decision situations. Larkin (1989) has called this effect display-based problem solving because the availability and form of the information displayed can affect problem solving. For example, Russo (1977) found that a table of unit prices for an entire category of food facilitated price comparison and decision making as compared to unit prices displayed with each item, although unit prices are calculated by item, not category. One reason for this improvement may be the reduction in working memory load when appropriate information is clustered. Thus, the tools used to do a task and procedural knowledge of how to do that task are not independent entities. The tool can facilitate the task procedures or, in the case of clumsy automation (Wiener, 1989), dictate conflicting procedures.

To solve the problem posed above I propose providing information displays that cluster and integrate information according to the expert decision maker's knowledge schema and procedural structure rather than according to a functional one. I hypothesize that such a system would lead to more efficient decision performance. What I mean by efficient is equal or better performance in a shorter time, with less effort. In the remainder of this chapter I will first report on an experiment that demonstrates the performance advantages for this idea and then I will discuss several military applications for the findings.

TESTING THE HYPOTHESIS

To test the hypothesis a complex, time-dependant (but non-military) test domain with multiple, conflicting goals was selected. The decision task was designed to have a one-to-one correspondence with key elements of the submarine problem. (One advantage of the non-military task was that many more experts were available. Additional evaluation verified the task validity.) Three information format schemes, alphabetical listing (format A), functional partitioning (format B), and procedurally based information-clustering (format C) were tested. Version C was designed by a bootstrapping procedure based on two individuals pilot testing versions A and B.

Three classes of dependent measures were used. The first was total time-on-task. The second reflected outcome performance, and the third measured processing activity. Results showed that version C lead to the most efficient performance. There was an interaction between performance measures and measures of processing time and processing effort. Functional partitioning required greater effort for limited performance improvement over the alphabetical format. Thus, the right organization scheme can provide the support for improved cognitive performance.

There are many possible partitioning schemes for categorizing and organizing information. Like the contents of a computer directory, tools on a workbench, or merchandise in a store, information in a decision support system can be organized by many attributes, including size, purpose, time, or order of use. The different organizational structures facilitate achieving different goals. Random placement speeds cleaning-up after a project, but organization by purpose speeds retrieval of tools from a workbench.

Phase 1: Information Organization: The experimental task was simulated, on-line, college course scheduling. This task has many elements in common with the target task, dynamic decision making under uncertainty, but has many more experienced individuals to serve as testers. To simulate an event-driven environment, classes could fill while the "student" was selecting a schedule. When a planned course was filled, the subject had to reassess the situation and find a new course that fulfilled the other requirements. Elements of data history were important because previous semester's records, program requirements, and course prerequisites had to be reconciled. A set of sometimes conflicting goals further constrained choices (see Table 1). Lastly, of course, classes could not conflict with one another. To simulate the multiple sources of information, each function (e.g., instructor rating lists, course schedules, requirements lists, student history, course locations and distance maps, etc.) had its own information presentation. This task is not a simple scheduling problem because there is no single "optimal" or algorithmic schedule that solves all constraints and meets all the goals. It requires goal-driven decision making to achieve acceptable performance.

A scoring scheme was developed that operationalized each of these elements as values associated with accomplishing the goals and values for each of the choices (i.e., courses and instructors). It was predicted that scores would reflect the level of organization in the display schema.

Table 1: Goals, listed in priority order

- Register for 15-17 hours (5 courses).
- Try to fulfill requirements and prerequisites for both general education and your major. (Note that you may remain an industrial engineering major or select engineering psychology.)
- Try to schedule so that you have one full day or two half-days off. (One full day is preferable. Assume you have a job and will otherwise have to work on the weekend.)
- Try to get the best instructors possible. A list is provided of instructor ratings from a student survey.
- Try to avoid 8 am classes.

Apparatus Design Methods: Establishing the correct information structure can be an iterative, almost circular process as procedures can change when tools change. The question herein is not *how* to design displays, but what are the *effects* of information organization on performance. Three prototype information presentation schemes were developed. Versions A and B were modeled on the registration materials used by many pre-internet generations of students. These included student record; a catalogue listing general degree requirements and specific requirements for each major, course descriptions; prerequisites for each course; a schedule of courses for the upcoming semester; a student schedule sheet for recording selections; and an informal rating of faculty published in the student newspaper. Students had to determine the availability of seats for each course, by going to each department. For this experiment, this last step was consolidated into a single list. Selecting courses required multi-way comparisons among the sources of information, and across many pages in each. Information in each of the sources was structured differently.

Although the majority of these materials were organized by academic department, other schemes were also used, including listings by time, by course number, and alphabetically, by name. Version A was intended to serve as a baseline of minimal performance and maximal task time. Armchair analysis suggested that organization alphabetical listings by course title and listing by course number was unlikely to match anyone's procedural or declarative knowledge schema for this kind of information. Thus, it was used for version A.

For Version B, recall and interview with individuals who had attended college prior to the computerization of registration led to organization by information type (student record, departmental course listing, requirements, etc.), much as it had been in my student days. To prevent the participants in Conditions A and B from reorganizing the information by opening multiple windows, the metaphor of an electronic book was used, with "pages" for each kind of information above. The book could only be open to one page at a time.

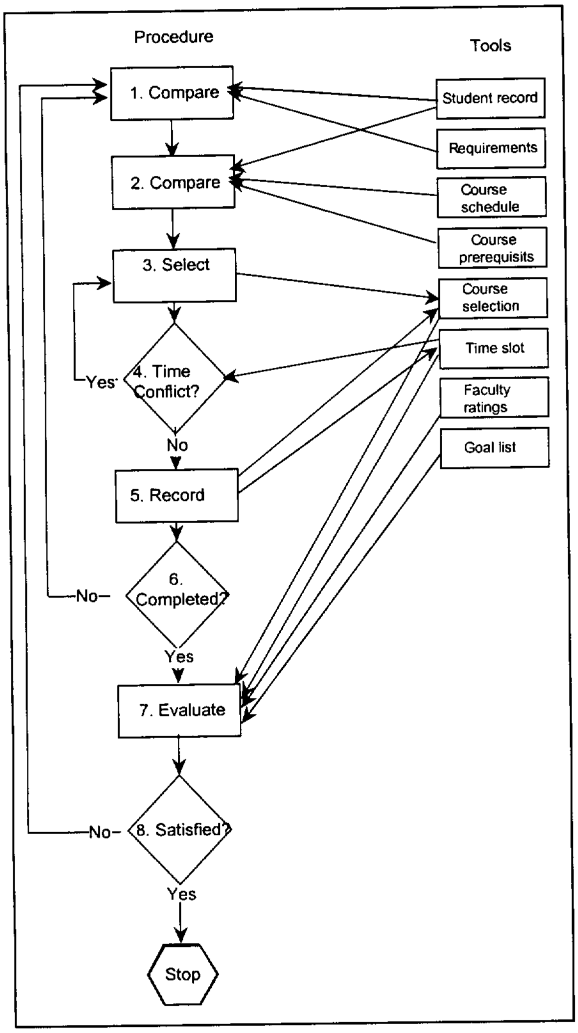

Figure 1: Steps used by a typical student to complete a course schedule.

Version C was modeled on modern computer registration. This was designed, not by attempting to recreate a historic artifact, but by a bootstrapping procedure based on two individuals pilot testing versions A and B. Figure 1 shows all of the steps used by these individuals[1]. The many steps used different subsets of the available information (see Figure 1). These subsets were used sequentially, as a single cluster, although the order was not invariant. For example, two clusters were used to make initial course selections. These were (1) requirements and student record of courses already taken, and (2) course prerequisites, student record, and times of potential courses.

The same information could be used by several steps. To accommodate all possible steps in this procedural approach to information organization, the clusters of information most often used by a single step were displayed in the same window or in other windows that could be open simultaneously. Thus, only eye movements were necessary to obtain all the information used by any step.

[1] Not all steps were used on every trial.

PHASE 2 BEHAVIORAL EXPERIMENT

Participants: The two a priori requirements for participants were that they be recent college students with a minimum of eight semesters and that they had registered for college classes within the past five years. They could be considered experienced at the putative task. There were 10 women and 26 men evenly distributed across the three conditions. They had last registered for college courses an average of 2.86 years prior to the experiment. Educational level of the sample ranged from bachelors to doctorate degree. The experiment used a between subjects design with twelve participants per group.

Apparatus and materials: The task was a second year college registration. Participants were given goals, student records of course and grade history, prerequisites, a campus map with walking times, and instructor ratings. The task was timed and courses closed, dependent on the elapsed time. All experimental material was developed in Supercard and presented on a Macintosh computer with a 19 inch color display. Conditions A and B used a booklet-like format with only a single page visible at a time. The page numbers in the Table of Contents were hypertext links to the listed information. Categories are listed in Table 2.

Table 2: Categories of information in Table of Contents

- Goals
- Student record
- General requirements
- Departmental requirements for Major
- Course Prerequisites
- Courses Schedule
- Campus map
- Table of Instructor ratings
- Table of class size and seats remaining

In condition A, all information in the course schedule and prerequisites sections was listed in alphabetical order. Thus, Introduction to Psychology followed Introduction to Physics. As courses were not listed by course title (only course number) in the requirements and student record sections, this format required a search information retrieval strategy. In condition B course schedule and prerequisites were listed by department, and sequentially by number within department.

Condition C used the procedural format developed in Phase 1. It used a computer registration analogy with access to information via a menu. Multiple movable windows could be open simultaneously. These were scrollable and resizable when required (e.g., course schedule, registration card, and any other card with more than about 10 lines of information). As the screen and text were of the same size, approximately the same quantity of information was visible in all conditions.

In all three versions of the task, the program recorded windows opening, buttons being pushed, typed text, and the time (in ticks) associated with each interaction.

Procedure: The experiment took place in a small, sound-damped, experimental room. All instructions were presented on the computer screen. Participants were given introductory instruction on manipulation of the objects used in the program and on the task. There was a practice task for each condition that duplicated all of the screens, interactions, and information types. During the practice and before the actual experimental trial, participants were invited to ask questions, however, questions about strategy were not answered. No questions were answered after the experimental trial began. At the end of the experimental task, participants were asked to complete a computerized questionnaire and were debriefed. The questionnaire was designed to ascertain recall of relevant information, task strategy, computer and college registration expertise, and any comments about the experiment.

STATISTICAL RESULTS

Three classes of dependent measures were used. The first was total time-on-task (T). The second reflected outcome performance (P), and the third measured processing activity (A).

Performance was defined as the summation of the following four performance measures: the number of credits successfully registered (P_1), the sum of the requirements scores for all courses registered (P_2), the sum of the scheduling difficulty scores for all courses registered (P_3), and the average preference score for the instructors of all selected courses (P_4). Scheduling difficulty was computed as the number of seats in courses that would satisfy requirements times the number of credits, weighted by the scheduling priorities given in the goal list. Each of the four scores was determined a priori and was reflected in the goal set given to the participants.

The processing measures captured various aspects of the effort participants put into the task. These included, number of registration attempts (A_1), number of class close-outs (A_2), number of windows used (A_3), and number of times the subject iterated back and forth, between any two windows (A_4). One full cycle from window a to b to a to b was counted as one iteration.

These measures were combined into an overall efficiency measure. Efficiency, E, was defined as the ratio of mean overall performance, $m_{(Pi)}$ to mean amount of processing, $m_{(Aj)}$, plus total time-on-task required to achieve that level of performance, T:

$$E = m_{(Pi)}/(m_{(Aj)}+T) \quad (1)$$

The groups did not differ on any of the measures of computer experience or college registration experience. Table 3 shows means and standard deviations for all behavioral measures (T, P, A, & E). To facilitate comparisons among measures, all scores were transformed into standard scores with a mean of 50 and a standard deviation of 10.

Time-on-task: While means were not significantly different among groups, variances were large, time-on-task did contribute to individual performance differences. To account for differences in time taken by individual participants, performance and processing measures were computed per unit time. While not statistically different due to large variances, the trend was surprising. Versions A and C appeared equally fast (Figure 2).

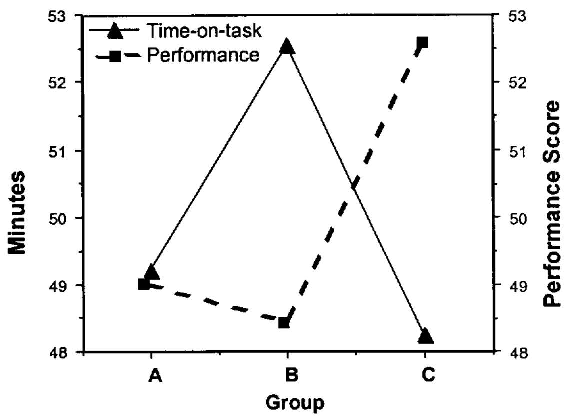

Figure 2: Mean time-on-task and mean performance.

Performance Measures: Overall performance, superimposed over time-on-task shows the relationship between the two. Those using version A found it so difficult that they basically gave up trying perform well. They just wanted to complete the task quickly. People using version B found that they could complete the task, but it took considerable time and effort.

Decomposing the performance measures provides the supporting detail necessary to understand this effect. The performance measures appeared to be composed of two compound measures that behaved very differently from one another (see Figure 3). The first,

$P_{1,2}$, was composed of the more concrete performance measures; P_1, the number of credits successfully registered and P_2, the sum of the requirement satisfaction scores for all registered courses. The tasks represented by these measures were essential for completion of the course schedule and did not reflect differences in performance. They replicated minimal or baseline performance. Although there appears to be a slight trend toward better performance for groups B and C, this was not significant, $F<1.0$.

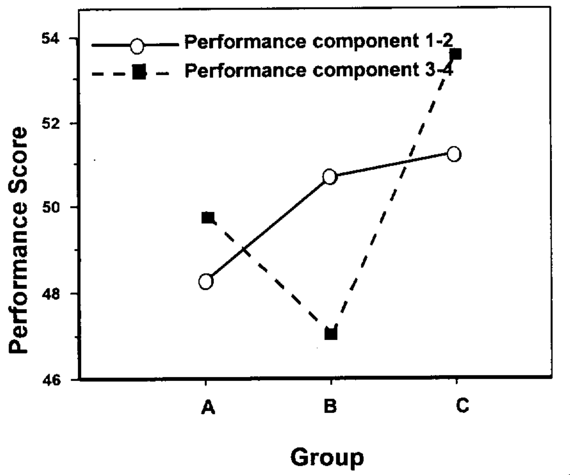

Figure 3: Mean performance on two compound measures for each display format.

Processing Measures: The process measures also showed two patterns of behavior (see Figure 4). For ease of analysis and discussion, these shall be called $A_{1,2}$ and $A_{3,4}$, with the understanding that the two components of each compound measure displayed the same pattern of results. The first compound measure was composed of measures A_1, registration attempts and A_2, number of close-outs. These are both indications of difficulties with the task, rather than the information format. There were no significant differences among the conditions on this compound measure, $F(2,33) = 1.71$, n.s.

Table 3: Means and standard deviations for all measures for all groups.

	Alphabetical		Functional		Procedural	
	M	SD	M	SD	M	SD
Time on task	49.24	9.76	52.54	10.62	48.21	9.94
Performance Measures						
P_1	48.40	11.77	50.97	6.36	50.60	11.62
P_2	48.33	12.20	50.17	8.87	51.52	9.23
P_3	49.65	10.07	47.69	11.35	52.59	8.73
P_4	49.67	11.46	46.61	8.60	53.82	9.29
Process Measures						
A_1	48.89	5.43	53.47	15.04	47.21	5.76
A_2	51.01	12.33	52.15	10.93	46.44	3.95
A_3	55.78	8.98	54.21	7.60	40.02	3.92
A_4	56.65	9.65	53.84	6.37	39.51	0.42
Efficiency Ratio						
	0.48	0.07	0.47	0.09	0.58	0.08

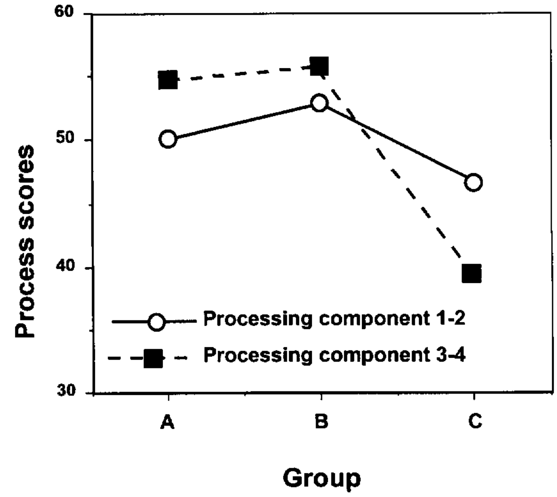

Figure 4: Mean processing score on two compound measures for each display format.

The second compound performance measure, $P_{3,4}$, was composed of more difficult, evaluative and integrative tasks; P_3, the sum of the scheduling difficulty scores for all courses registered, and P_4, the average preference score for the instructors of all selected courses (see again Figure 3). These measures appeared to reflect an added effort to perform well, when possible. $P_{3,4}$ showed a paradoxical dip in performance with the functional display organization, B. This quadratic trend was marginally significant, $F(1,33)=4.07$, $p=.05$.

The second pair of processing measures; A_3, number of windows and A_4, number of iterations, are related to information accessibility and congruence with procedural needs. If the information format does not match the sequences used by procedural knowledge, the individual must collect it from where it is (indicated by A_3) and then create the sequence in working memory (encoding and sequencing indicated by A_4). There were significant differences among the groups on this pair of measures, $F(2,33) = 43.04$, $p<.001$. This was a very robust effect with $\eta^2 = 0.72$ and, in a post hoc test for trend, the quadratic trend was significant, $F(1,33) = 13.104$, $p<.005$.

Efficiency: The processing, performance and time-on-task measures combined to evaluate the effect of information organization of decision making efficiency. Participants who used the procedural information format were significantly more efficient in their decision making than were those using either of the other two formats, $F(2,33)=7.29$, $p<.005$ (see Figure 5). This was a robust effect, with $\eta^2 = 0.32$. In a post hoc test for trend, the quadratic trend was significant, $F(1,33) = 4.32$, $p<.05$.

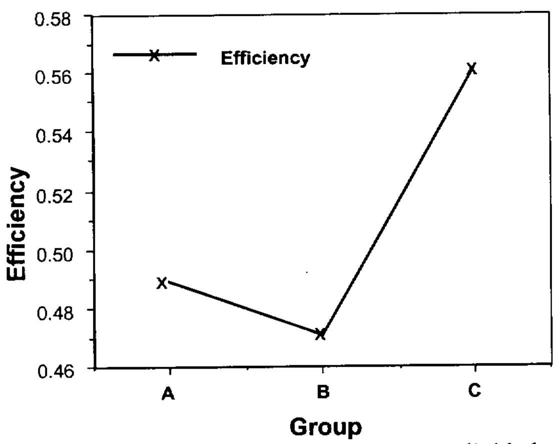

Figure 5: Efficiency (performance divided by processing effort and time) for each of the three display formats.

PROCEDURAL ANALYSIS

The first task of the procedural analysis was to evaluate the relationship between overall performance and overall procedural processes. This relationship can best be understood by examining Figure 6. As can be seen, there was an inverse relationship among these measures. Processing variables were moderately predictive of total performance score, $R^2 = 0.42$.

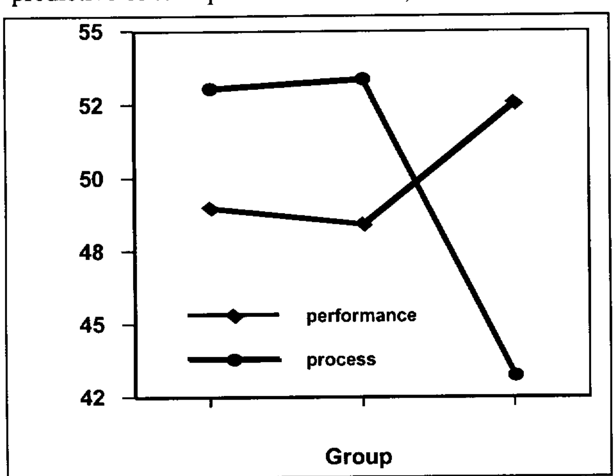

Figure 6: The relationship between performance and process measures for each format.

Iterations: The iteration measure is a reflection of the efficiency of procedures used by participants under each of the three conditions. In conditions A and B, participants physically iterated between pairs of information while in condition C they typically positioned information windows so that information used in the current step could be accessed with eye movements and did not require mouse actions. A typical pattern for the participants in condition A was to iterate between the schedule page and virtually every other page. However, there were numerous iterations among other pages. For participants in condition C, virtually all of the iterations were between the schedule page and one of the pages listing course schedules. There were very few iterations for participants in condition C and these were different for each subject. Figure 7 shows typical patterns of iterations.

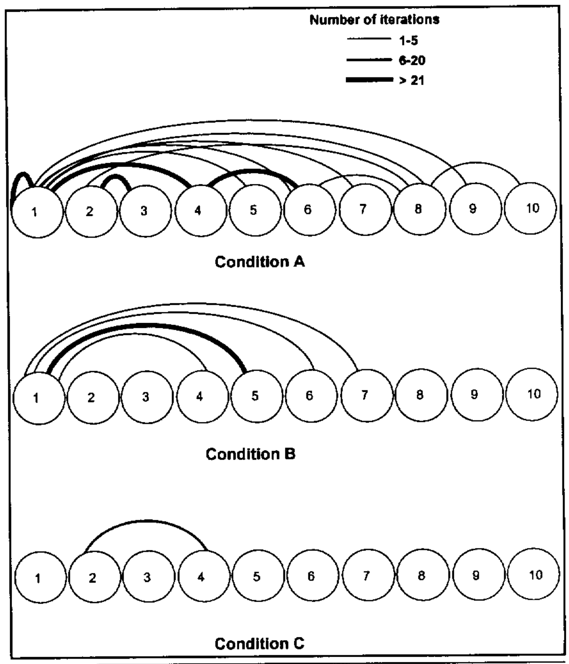

Figure 7: Typical patterns of iterations for participants in each of the three conditions. Node #1 is Table of Contents.

Sequences: Just as the number and pattern of iterations differed by condition, other aspects of performance differed by condition. Unfortunately, neither verbal protocols nor eye gaze data were collected so one can only infer goals. Self reports in the follow-up questionnaire shed no light on the question because there were no differences among groups and because participants often reported placing no weight on a source of information that they examined frequently or, conversely, placing heavy weight on information that they never accessed.

Sequences of pages (Conditions A and B) or windows (Condition C) provide insight into goals and validation of the procedure described in Figure 1. Several of the sequences were found in all conditions including those used for procedures 1 and 2. Only participants in Condition C were able to see a listing of courses by time slot. The majority of them used this display, but only for the last one or two course selections.

The sequence of the requirements listings either preceded or followed by student record (procedural step 1, Figure 1) is used to illustrate differences among the groups. Groups A and B examined requirements an average of 5.85 (SD = 1.29) and 6.75 (SD = 0.94) times, respectively while group C reviewed this important information an average of 10.75 (SD = 1.01) times. Moreover, review of this pair of windows was not evenly distributed across the duration of the task. It appeared more frequently prior to early course selections. Apparently as the possibilities narrowed, many participants chose to skip step 1 in the procedure.

DISCUSSION

Providing guidance for the development of interfaces that support efficient (proficient and timely) decision making was a major motivator for this study. The most obvious conclusion is that these results indicate the importance of information organization that is congruent with procedural knowledge. Moreover, they show the impact of such organizational schemes on efficient performance. A more detailed examination of the data indicates that differences in support for procedural knowledge differentially change task procedures. Evidence for these differences are provided by all three sets of results reported here, performance score components, processing activity components, and the iterations picture.

Performance: Differences in the two compound performance scores, $P_{1,2}$, (the more concrete, required performance measures) and $P_{3,4}$, (the optional evaluative and integrative measures) suggest that motivation plays a subtle role in the equation. Performance on the $P_{1,2}$ measure was flat, but with large individual differences. A ceiling effect may have contributed to the lack of systematic differences.

$P_{3,4}$ performance was clearly affected by some aspect of the tool. As these measures related to qualitative performance, they might reflect the ease of use for the different organizational schemes. Clearly, Version C provided the cognitive affordances for better performance. The processing scores (see below) contribute to this conclusion.

Surprisingly, performance was not poorer on any measure for Condition A. Although that version of the task was intended to provide the *least* support for procedural knowledge, it did not differ from the traditional, department (like-with-like) organizational scheme. Might it be true that any information organization that is not congruent with procedural knowledge restricts performance?

Processing Activity: As with the performance compound measures, differences in the two compound processing measures showed different patterns. Compound measure $A_{1,2}$ reflects the task difficulty and, not surprisingly, did not differ among the three conditions. This lack of difference verifies that the task *could* be accomplished with any of the three versions.

Compound score $A_{3,4}$ measures physical interactions and reflects congruence between procedural knowledge and affordances in the tool. The systematic differences in $A_{3,4}$ indicate that the task was more easily and efficiently accomplished with version C. Again, there were no differences between versions A and B.

CONCLUSIONS AND IMPLICATIONS FOR BATTLESPACE MANAGEMENT SYSTEMS

We have seen that an information organization scheme based on procedural knowledge (Condition C) can facilitate performance at a complex, time-driven task. Moreover, performance without a reasoning-congruent information scheme hindered performance, regardless of the information organization. When the decision maker must expend both time and cognitive resources to compensate for the tool, those resources are not available to perform the task. Thus, the right organization scheme can provide the affordances for improved cognitive performance.

How would this work in a Battlespace Management System? As I am most familiar with submarine systems and with meteorological systems I'll use one of those, the submarine, as an example. The submarine systems include multiple sensor performance prediction algorithms, sonar sensors, target-motion-analysis algorithms, and battlespace displays. These tools correspond to the functions of search, detect, track, classify, localize, etc. However, when we examine the behavior of expert submariners, they do not limit themselves to this sequence (Gray, Kirschenbaum, & Ehret, 1997; Kirschenbaum, 1992). They iterate among the tools as they employ specific information gathering strategies. Thus a Battlespace Management System for submariners might, for example, facilitate comparing the output of a target-motion-analysis tool to the sonar traces at that bearing. Would the proposed course, speed, and range actually fall within the sonar trace, as displayed? How well would it match the region where the sonar could detect? We are currently building displays to answer these questions by showing these detection regions in 3-D, along with the possible tracks. Thus, we facilitate the very comparison procedures that we have observed submarine decision makers using.

The submarine 3-D display work is just beginning. The effects on performance have yet to be tested. The approach is much like that used in the experiment reported above. If the results replicate in this domain differences in affordances for procedural knowledge will again support differences in performance. While information systems have always been developed by analyzing perceived needs, a radically different suggestion is to design information management decision aids the way new walkways are sometimes planned. That is, where natural paths occur because of repeated use by pedestrians, constructed (concrete, macadam, gravel, etc.) pathways are built. These are not planned a priori, but develop from use. Only after the grass has been worn, are constructed paths built. In the same way, the information organization schemes should provide affordances for knowledge in the head -

- the procedural paths we create through the task and the information.

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Pilot's assistant in tactical transport missions -

Crew Assistant Military Aircraft CAMA

(April 2000)

Dipl.-Ing. Andreas Lenz
Prof. Dr.-Ing. Reiner Onken
University of Armed Forces Munich
Werner-Heisenberg-Weg 39
D 85577 Neubiberg / Munich
Germany
Tel. -49-89-6004-2233 or -3452
Fax -49-89-6004-2082
andreas.lenz@unibw-muenchen.de reiner.onken@unibw-muenchen.de

Summary: New information technology promises more information and advanced automated functions in future cockpits of military aircraft. However the cognitive human capabilities stay the same. This may result in an overload of the human pilot. Cognitive assistant systems are being developed to compensate for this mismatch. This paper introduces principals of cognitive systems which exhibit human-like capabilities as interpretation and diagnosis of the situation, planning and decision making. Furthermore, CAMA (Crew Assistant Military Aircraft), a prototype of a cognitive assistant system, will be introduced. CAMA's functionality will be shown and some results from flight simulator test runs will be presented.

Motivation: Environment and scenarios of military transport missions have changed over the last few years and will definitely undergo even more changes in the next decade. New information technology, including telecommunication as well as hardware which is continuously growing more powerful will find its way into the future military aircraft. Online data of upcoming threats, detailed weather information, terrain data and knowledge about weapon systems will be available. Combined air operations with participation of AWACS, fighters, bombers and transport aircraft are likely with the need for more communication.
There is a rising amount of mission-relevant information, that has to be processed by the human operator who is also in charge of flying the aircraft. Considering the complexity and manifold of automation in current cockpits and even more in those of the next generation it can clearly be seen, that it will become more and more difficult for the human to keep situation awareness and perform all the tasks in an efficient way without errors.
This leads to the central question:

How can we make the best use of the potential given by the new technologies without overloading the cognitive capabilities of the human operator ?

There is an approach where automation in the conventional way is being added to the cockpit, hoping for increased productivity and effectiveness. As we know from experience, however the conventional automation can increase safety only up to a certain level. Further increase of complexity in the conventional way can lead to a safety decline as shown in figure 1 in its principal relationships.

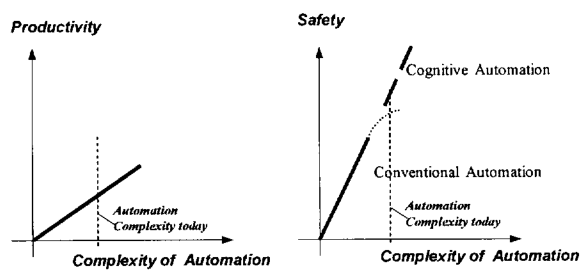

Figure 1: The Effect of Conventional and Cognitive Automation on Productivity and Safety

Recent accidents of commercial aircraft with state-of-the-art "conventional cockpit automation" provided sufficient evidence for this particular consequence. [1] identifies besides complexity as such also other design elements more or less as part of complexity like

- coupling of automated features,
- autonomy with unexpected self initiated machine behaviour and
- inadequate feedback

which are typical causes for respective mishaps. In military aviation the situation can be expected to be critical due to permanently increasing requirements for information processing.

Cognitive automation: How can this situation be dealt with? The critical point is, how automation can be done in an effective manner. Automation should not be a replacement for the pilot, but instead should work in a cooperative way with the pilot. In the ideal case it

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should work like a kind of "electronic crewmember", with the cognitive capabilities like those of the human, but without all its possible deficiencies.
[2] postulates *basic design requirements* founded on these cognitive capabilities:

Requirement (1) is to avoid failings in situation awareness and reads:
It must be ensured along with the representation of the full picture of the flight situation that the attention of the cockpit crew is guided towards the objectively most urgent task or sub-task as demanded in that situation.

Requirement (2) is to avoid overcharge in decision making/planning/plan execution and reads:

Situation awareness might have been achieved and still a situation with overcharge of the cockpit crew might come up. In this case the situation has to be automatically transferred into a situation which can be handled by the crew in a normal manner.

"Cognitive automation" is the only way to ensure increase of productivity through automation without loss of safety (see fig.1).
The difference between cognitive and conventional automation can also be illustrated by Rasmussen's scheme of human cognitive behaviour [3].

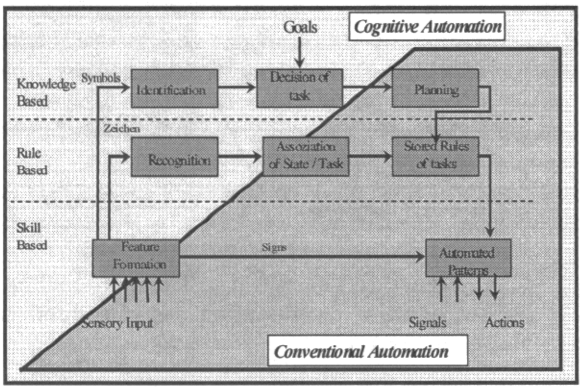

Figure 2: Conventional vs. cognitive Automation [4]

As figure 2 shows, conventional automation covers nearly the whole of skill based human behaviour. The rule based behaviour can only partly be covered, and on the knowledge based level only planning calculations can be provided by conventional automation.

Cognitive automation comprises the entire rule and knowledge based level, as well as the skill based level, thereby giving the system human like capabilities to:

- independently assess the current goals of the crew, as well as information about the aircraft, the environment including the tactical situation, the weapon systems and the aircrew activities
- understand the flight situation by independently interpreting the situation subject to the goals
- detect the pilot's intents and possible errors
- detect possible conflicts of current plans but also the opportunities arising from the changing environment
- know which information the crew needs
- support necessary re-planning and decision making
- initiate a natural, human-like communication to match the system's internal pictures of the situation with those of the pilot.

The symbiosis of cognitive automation combined with the strength of the human will lead to a more efficient and safer mission execution

The Cognitive Process: To realise the cognitive approach as a technical process human cognition provides a good guideline. The following core elements can be identified:

- Situation monitoring (perception and interpretation)
- Diagnosis of the situation
- Decision making and/or planning
- Execution/activation

They are forming the cognitive loop as shown in figure 3. The environment of the cognitive assistant, which is named the real world, presents stimuli, which can be detected by different kinds of sensory systems. Both the environmental stimuli outside and inside the cockpit are taken into account. This represents the *situation monitoring* element, which comprises the process of perception of all relevant situation features. This is closely interrelated with the process of situation analysis in order to achieve a certain level of abstraction, thereby establishing situation-relevant "objects" which help to understand what is different

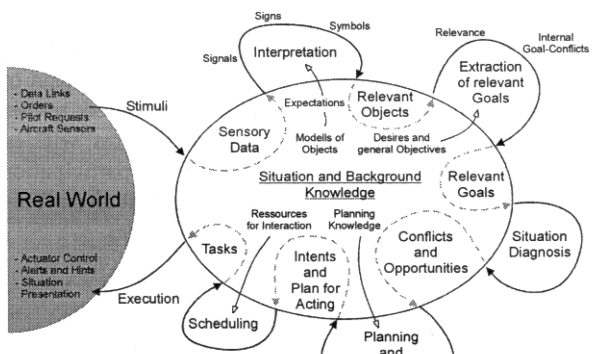

Figure 3: The Cognitive Loop [6]

between the expected and actual situation. These differences are dealt with in a higher level of abstraction by the so-called *situation diagnosis* process. The differences are evaluated against given objectives, the *relevant goals*, which are known to be pursued during the mission, and which are the same the aircrew has in mind. Only the knowledge about these goals makes situation awareness possible in the technical

cognitive loop. Thereby conflicts and/or opportunities may be detected which may call for immediate actions or some flight plan changes.
In the latter case a *planning process* is activated to generate alternatives for interim-goals, plans, and actions. In compliance with the given overall objectives, the most appropriate ones are chosen for proposals.
Concerning the assistant system, the *execution* element of the cognitive process plays a very central and important role, as it includes the communication with the crew. It is carried it out on the basis of profound internal knowledge about what information the aircrew is looking for, why and when. On the other hand, the crew should at any time be able to ask for certain information within the system. A sophisticated MMI is required to accomplish this task.
It is also taken into consideration that the crew may react different compared to the systems proposals, because certain factors were not taken into consideration at system design time. Thereby, new stimuli are generated for the cognitive loop, which starts again and copes with the crews action. The feedback via these stimuli creates a kind of implicit communication.

CAMA – The Prototype of a Cognitive Assistant System:

Military transport missions put great demands on the crew. The typical scenario is composed of IFR and tactical flight sections, as shown in figure 4.

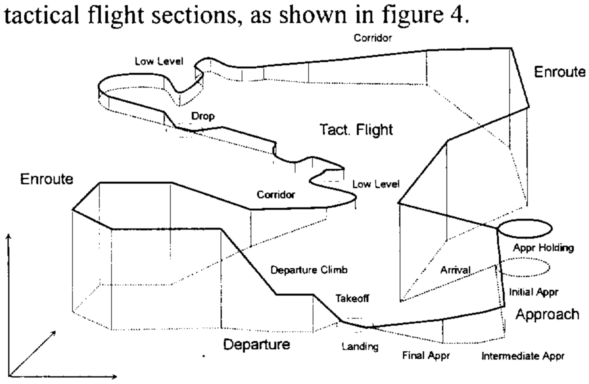

Figure 4: Mission Profile

While flying IFR, the aircraft may operate in a high density airspace. Separation to other aircraft has to be ensured. The tactical scenario is entered via a transition corridor. Constraints in time and space have to be met. Tactical flying will be mostly low level flying, using terrain masking, even under adverse weather conditions. Additionally, the scenario changes at a high rate along with quick reaction required at times. Concerning these conditions, technical cognitive assistance for the flight crew seems to be very promising.

Therefore, the German DoD started a program, called CAMA (Crew Assistant Military Aircraft), in order to have demonstrated the power of cognitive automation for transport missions. CAMA as a prototype cognitive assistant system has been developed by the University of German Armed Forces Munich in close cooperation with DaimlerChrysler Aerospace, ESG (Elektroniksystem und Logistik GmbH) and DLR (Deutsches Zentrum für Luft- und Raumfahrt) (see [7] [8]).

Structure and Functionality of CAMA:

The Crew Assistant Military Aircraft provides functionalities in compliance with many parts of the cognitive loop. Again as depicted in figure 5 the system is embedded in the real world environment. Information about this environment can be perceived by means of sensors and data links.
The outer layer of CAMA performs perception and interpretation of the relevant situation elements of the real world. The process of ***environment interpretation*** as well as the ***interpretation of the aircraft state*** provides information about the actual weather, the proximity to the terrain, other aircraft, as well as the current state of aircraft subsystems. Tactical information which consists of the mission task, ingress and egress corridors and actual threat situation may be fed into the system. Additionally, data from computer vision systems are included for machine perception of relevant obstacles like landing strips and obstacles on uncontrolled strips under low visibility conditions.
All these pieces of relevant information are put together to form a central situation representation that provides all the data which other CAMA modules might need or which are produced for further processing like the ***evaluation and the interpretation of the pilot's action.*** This core element of CAMA forms a close functional relationship with the inner functional layer of the system for diagnosis and detection of conflicts and opportunities. The elements of the central situation representation that represent the relevant objects of the real world are evaluated against the expected behaviour of the pilot, the predicted state of the aircraft and against the overall mission objectives.

In order to monitor the pilot's behaviour the assistant system needs a representation of the expected pilot actions. In CAMA a normative model [9] describes the ***pilot's behaviour*** close to that as documented in handbooks and air traffic regulations. An adaptive model [10] covers behavioural traits of the individual pilot flying. If the actual pilot behaviour differs from the internal representations of CAMA then it can be classified into either ***errors*** or ***intents*** (see [11] [12]) This classification is based on the representation of the mission objectives and flight plan goals. These can be explicitly stated by the pilot as inputs via the MMI or can be implicitly contained in the pilot's intent which is continuously monitored by CAMA.
If the pilot behaviour is classified as an error a warning message is generated and a corrective action is

proposed to the pilot. Upon a detected intent the internal plan is adapted accordingly. Thus an implicit communication between the pilot and the system takes place, which allows the pilot to react to the current situation without having to tell the system explicitly.

derived from the mission order (e.g. entrance corridors to gaming area, drop-point, time over target etc.). A 'takeoff to landing' mission flight plan is then generated. The IFR flight plan as part of it, for example, includes the lateral flight path segments, the

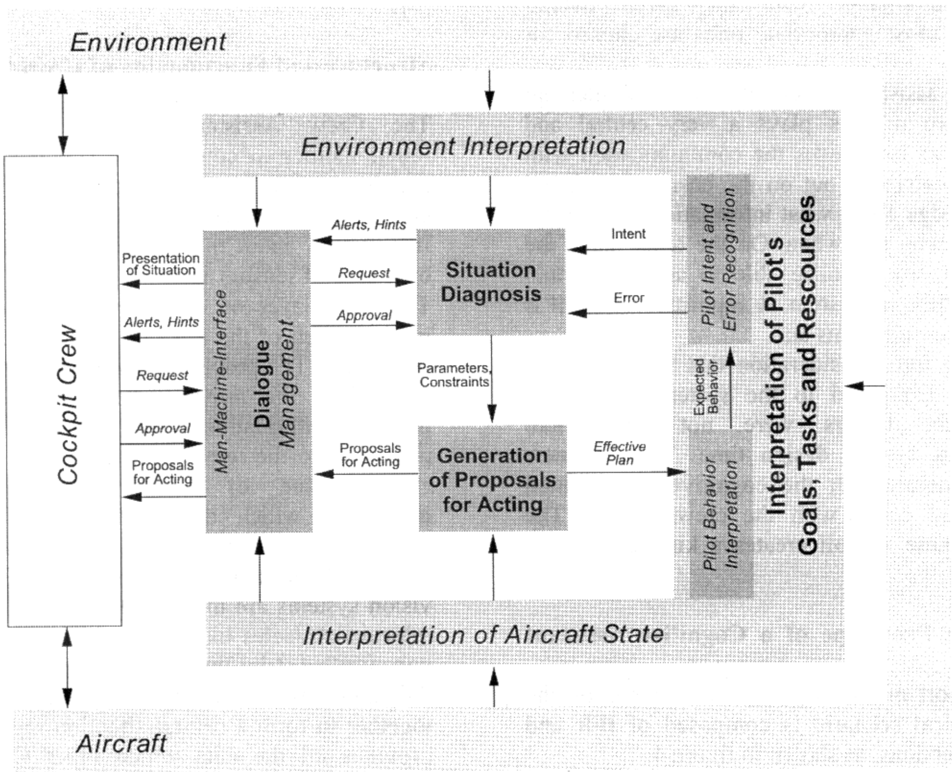

Figure 5: Functional structure of CAMA

vertical profile, time estimates and fuel planning [13] as well as information from a navigational database. Mission constraints which may change during the flight (e.g. a changed exit corridor from gaming area) or ATC instructions are considered during the planning process. If the mission order leads into an area with hostile radar coverage, the Low Altitude planner (see [14] [15]) is started accordingly, generating a minimum risk route with a maximum probability of survival in a hostile environment. This is achieved by avoiding threatened areas if possible, minimizing the exposure to unknown threats and keeping the aircraft clear of terrain. Therefore the mission constraints, the tactical elements and the resulting threat map, the terrain elevation data and the aircraft performance data are all taken into account. The generated routes are passed to the crew and are being accepted from them , modified or rejected respectively.
The calculation is done in terms of only a few seconds, always giving the pilot an idea of what would be a good plan in the current situation.

The advanced functionality of CAMA requires a sophisticated user interface to let the pilot make advantage of the system capabilities. Care has to be taken in the design of the MMI, not to produce an extra cognitive workload.

In case of a possible traffic conflict, for example, CAMA detects that the actual behaviour does not comply with the 'safety' objective and issues visual and acoustic advice as part of the Traffic Alert and Collision Avoidance Systems (TCAS).

Ground proximity is continuously monitored. Therefore, all possible flight trajectories, achievable by full exploitation of the aircraft performance capabilities, are checked for terrain avoidance (using a Digital Elevation Data database). Again a warning is given, visual and by voice. In addition an evasive trajectory is generated.

CAMA also generates ***proposals for acting*** as part of the conflict resolution which involves planning and decision making support. This functionality ranges from very short term planning e.g. collision and terrain avoidance to long term strategic planning. This enables the assistant system not only to detect the possible conflict, but to generate a conflict solving strategy. Again all relevant data needed is passed over from the situation representation module. In case of overall flight planning all accessible information about the flight is passed to the mission planner. This includes mission oriented goals and constraints that can be

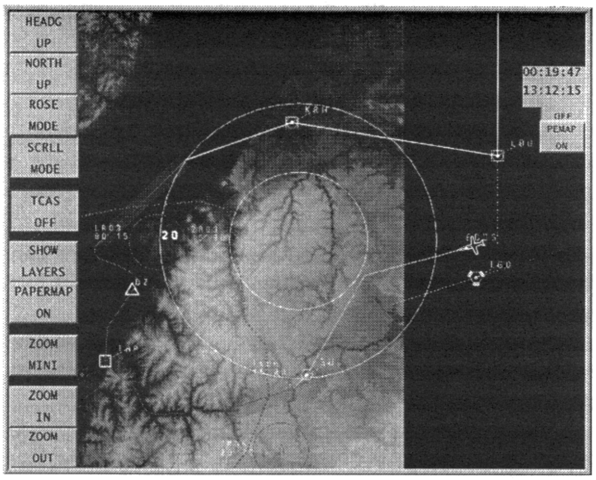

Figure 6: CAMA Nav-Display with Terrain and Tactical Elements

The ***Dialogue Management*** module [18] of CAMA ensures that the communication is provided to support situation awareness in the best way possible in all flight conditions. It is based on the multimodal approach, which means that all pilot inputs can be performed by speech, touch-sensitive screens as well as conventional line select keys or switches. Output makes use of the currently available display technology and is presented by means of three high resolution color displays. Speech output is used in parallel to textual messages. The simple graphical user interface delivers a good usability already after a short introduction to the system.

Pilot inputs can be:
- Request of flight planning actions
- Activation, modification or rejection of proposals
- Activation of actions related to warnings
- Retrieval of information
- Autopilot operations
- Configuration of the MMI
- Radio management

CAMA outputs can be:
- Presentation of calculated flight plan proposals in graphical as well as textual form
- Situation presentation including tactical and threat information
- Warnings about detected conflicts
- Recommendation about explicit actions
- Messages in reply to requests
- Acknowledgement of speech input
- Presentation of complex actions like briefings, checklists etc.

Several MMI devices provide support for the flight guidance task. For low level flying under difficult weather conditions the primary flight display can be switched to a 3-dimensional presentation of the surrounding environment [13].

Results of Simulator Flight Trials:
CAMA is integrated in the flight simulator of the University of the German Armed Forces, Munich. This simulator provides a wide field of view visual simulation. It is based on digital terrain and feature data and shows objects like rivers, streets, railroads and powerlines which makes it suitable for low level flight simulations based on terrestrial navigation. Three high resolution colour monitors with touch-overlay are used to display CAMA outputs. Also a number of realistic flight controls are available, including a throttle box, flaps, gear and spoiler levers, as well as an Airbus-type flight control unit for autopilot functions. All controls can be actively driven by CAMA on request of the pilot.

Figure 7: Test Flight Simulator

In November 1997 and May 1998 flight simulator test runs were conducted (see [17]). 10 German Airforce transport pilots (Airlifter Wing 61, Landsberg) were participating as test subjects. The pilots were tasked with full scale military air transport missions. This comprised a mission briefing with following takeoff from base, an IFR leg to the ingress corridor and a low level flight to a drop zone. The flight over hostile area contained a dynamic tactical scenario with multiple SAM stations (Surface to Air Missiles). After the drop was accomplished the flight was led to the egress corridor, followed by an IFR flight segment to the home base.
Each subject had to perform the mission three times. There was not much time needed for familiarisation and training on the system.
To set up an realistic level of workload several scenario items were put in the missions, which required an action by the pilot.

The IFR segment incorporated:
- Adverse weather conditions
- High density airspace (Other aircraft crossing the own flight path)
- Changing availability of landing sites
- ATC communication (e.g. clearances, radar-vectoring, redirection)

The tactical segment incorporated:
- Varying SAM sites

- Drop procedure
- Changed egress corridor
- Redirect to new destination

All ratings were given within a range from 1 to 7, where 1 represented the best and 7 the worst score. A choice of the results is shown in figure 8, 9 and 10, where the ratings are numbered due to the order of test runs.
A detailed and complete documentation of the test runs and its results is given in [17].

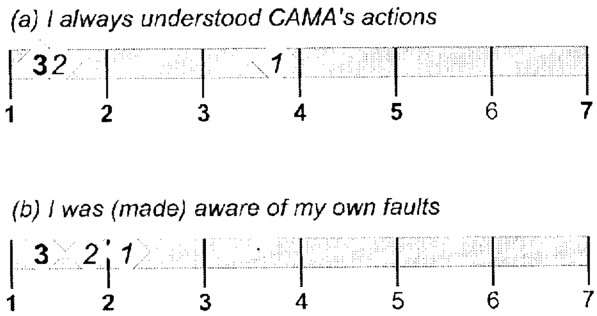

Figure 8: Evaluation of the Cooperative Approach of CAMA

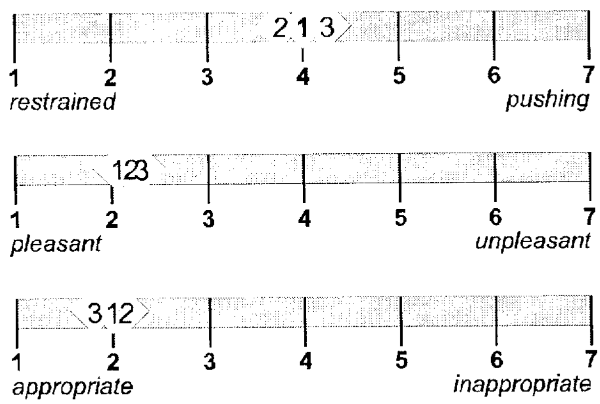

Figure 9: Acceptance of CAMA by Pilots

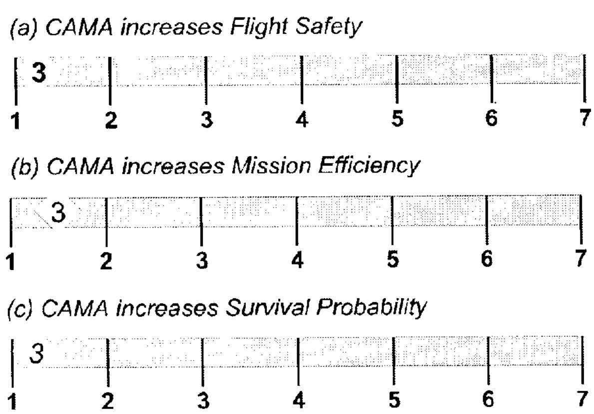

Figure 10: Overall Evaluation of CAMA

Especially the rating concerning the overall evalutaion as shown in figure 10 points out clearly the benefits of an assistant system like CAMA. Like the test subjects stated, CAMA:

- ***increases Flight Safety***
- ***increases Mission Efficiency***
- ***increases Survival Probability***

A more objective analysis of the flight simulator trials was done by [20] using an eye tracking system and a data recording tool. More information on this topic can be found in the respective paper in the same proceeding.

Actual research:

Figure 11: Experimental Aircraft ATTAS

Recently CAMA was being integrated in the in-flight simulator ATTAS of the DLR (shown in figure 11) and was successfully tested and demonstrated in several flight experiments in March 2000. Further trials are scheduled for November 2000. These flight tests comprised IFR and low level flight segments as they occur in a military air transport mission. Again subjects were experienced air transport pilots from the German Air Force. Data from sensor input as well as the internal system states were recorded, which will allow a replay of the conducted flights in the experimental flight simulator at the university of armed forces in Munich.

Conclusion: Future battlefield scenarios will be characterised by the availability of a greater amount of information. Onboard information processing puts great demand on the aircrew, which may lead to overcharging of the crew.
To cope with these changing conditions, the approach of a cognitive assistant system was investigated. It offers support to the aircrew regarding enhancement of situation awareness, handling of multifunctional tasks and situation-dependent balancing of workload for the sake of mission effectiveness and safety. It has become increasingly evident that this cannot be achieved without moving towards the cognitive approach.
The presented approach and its realisation in the prototype system CAMA has been demonstrated. The benefits are already demonstrated in the course of simulator trials and In-flight demonstrations.

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A CONCEPT FOR KNOWLEDGE-BASED USER SUPPORT IN NAVAL ENVIRONMENTS

Dipl.-Ing. Helmut Distelmaier, Dipl.-Ing. Gert Dörfel, Dr.-Ing. Bernhard Döring
Ergonomics and Information Systems Department (EFS)
Research Institute for Communication, Information Processing, and Ergonomics (FKIE)
Research Establishment for Applied Natural Sciences (FGAN)
Neuenahrer Str. 20, D-53343 Wachtberg-Werthhoven, Germany
Tel: [+49] (228) 9435 - 0, Fax: - 508
distelmaier@fgan.de; doerfel@fgan.de; doering@fgan.de;

Abstract

Technology pushes for sensor and weapon systems as well as for command, control, communication, and information systems have increased the amount and complexity of information available while the time to process that information has dramatically decreased. Additionally, recent changes in military situations and doctrines have given rise to the need for computer-based aids that can support human operators in getting situation awareness and reacting to novel complex and rapidly changing situations. A concept has been developed to support the members of the decision making team in combat information centers of the German Navy vessels by knowledge-based user interfaces. Such interfaces will ease the burden of the decision makers in all phases of the military command and control cycle and enhance the effectiveness of the decision making process in novel military scenarios, e.g., in Littoral Warfare, Crisis and Low Intensity Conflicts, or Missions other than War. The paper starts with a general problem description and a framework of operator support possibilities based on a hierarchical structure of human task performance with different levels of situational complexity. It follows the description of a generic support concept by means of knowledge-based user interfaces consisting of a knowledge-based assistance system and an interactive multimedia user interface. Finally, as an example the implementation of the conceptual work into a demonstrator of operator support in naval anti-air warfare situations is presented. With this demonstrator the effectiveness of decision making and action taking support by a knowledge-based user interface could be shown.

1 Introduction

Technology pushes for sensor and weapon systems as well as for all kinds of military command and control systems (C2/C3/C4I) have increased the amount and complexity of information at hand while the time available to process that information has dramatically decreased.

Additionally, in actual military operations, e.g., in Littoral Warfare, Crisis and Low Intensity Conflicts, or Missions other than War, operators who are responsible for planning and decision making are faced with natural dynamic situations which are characterized by extremely rapid changes in the tactical situation, highly uncertain information, and a large variety of potential situational hypotheses. These decision makers undergo high mental stress due to the need to respond quickly and accurately, or face potentially fatal consequences.

It may currently not be possible to design a system which can cope with all conceivable events in highly ambiguous situations, for instance, with those found in novel military operations. But it is already possible to develop a system that complements human's abilities in perceiving and assessing such situations as well as responding appropriate in unknown situations.

Operator support by intelligent and adaptive knowledge-based user interfaces is considered to be a viable approach to overcome some of those difficulties decision-makers are faced with when having to cope with complex command and control systems in novel military situations. Such user interfaces consist of a knowledge-based assistance system and an interactive graphical or multimedia user interface. They can support military decision makers in performing information gathering, information processing, and information entering in all phases of a command and control (C2) cycle, i.e., in situation perception (observe), situation assessment (orient), decision making (decide), and action taking (act).

2 Human Task Performance and Operator Support in Complex Situations

Situational awareness (SA), that is a reliable assessment of the situation in which a ship operates, is vital for the successful completion of its mission. To establish and maintain SA, information from own sensors or other sources of significant data and conditions must be processed. This information concerns the tactical environment as well as the own combat (sub)system(s).

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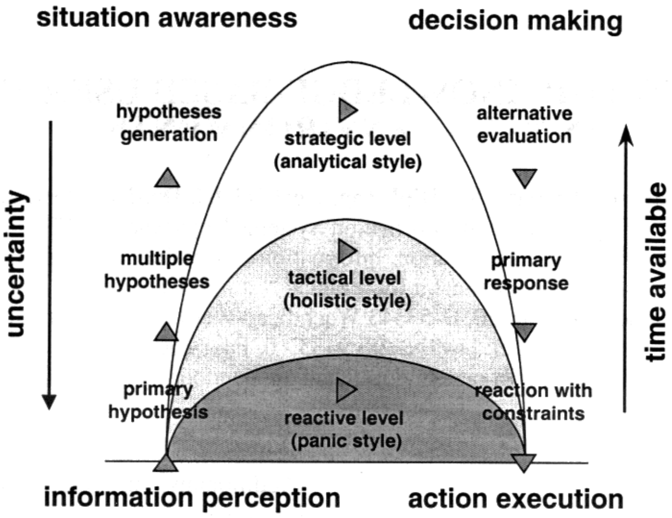

Figure 1: Situation awareness and decision making with uncertainty and time pressure

In order to provide a reliable information basis for carrying out missions, it will be necessary to assess and reassess the situation on a continuous basis. Normally, little is known about the operational environment with certainty. Therefore, to establish SA hypotheses about the behavior of both identified and unidentified objects as well as about the overall tactical and strategic situation have to be generated. Uncertainty and imprecision in observation and information gathering will quickly result in very large numbers of hypotheses that will have to be managed by human decision makers. This demand cannot adequately be satisfied under constraints of information overload and time pressure (Fig. 1).

When being confronted with complex situations three levels (styles) of decision making can be defined as reference points on a "cognitive continuum" [Amat, 1995]:

- reactive level (panic style) -
  in the case that SA may be incomplete or even very reduced because of time pressure and information uncertainty the decision making style will correspond to a panic behavior that leads to impulsive selection of a course of action based on a primary situation hypothesis.
- tactical level (holistic style) -
  familiarization and the expertise acquired play a crucial role in operator decision making. When the operator recognizes a situation as belonging to his catalogue of experienced situations, he associates to this picture a course of action. The first hypothesis that works is adopted and implemented. This holistic style of decision usually provides good results. Under high time pressure or mental workload most of the time holistic strategies will also be used with good but sometimes with less desirable results.
- strategic level (analytical style) -
  the analytical style corresponds to a "theoretical" strategy. It is the most time consuming and mentally demanding style. On this level an operator makes a detailed assessment of a situation, gathers the maximum of data, defines the problem, forms a list of alternate solutions to the problem, chooses selection criteria, ranks them by priority and selects the alternative having the greatest weight within the space defined by the selection criteria. The aim of this strategy is to find the optimum solution.

The task of gathering and correctly combining different types of data, information, reports, and messages and then drawing accurate conclusions still remains the responsibility of the military decision makers who are usually under great strain during tactical operations. Generic cognitive tasks to be performed by means of C2 systems are information gathering/situation perception, situation assessment, goal establishment, decision making/action planning, action command, and control of action accomplishment for goal achievement. These cognitive tasks describe the course of activities in military C2 cycles and in nonmilitary decision situations, too. Differences in situational familiarity, information uncertainty and time pressure are related to different cognitive processes corresponding with differences in control effort and time consumption. Effort and time increase from simple decisions with quick reactions for routine tasks in clear situations to task of higher complexity with cognitive demanding tasks in ambiguous situations.

For developing support systems that assist the operator in complex decision situations it is useful to obtain and apply a model of the human decision making and problem solving process. This model has not to be an exact reproduction of human cognitive processes. Rather, it should enable identifying possibilities for situation-, task-, and user-based assistance of the decision making and problem solving process. Such assistance should comprise information presentation for situation assessment, information processing for solution

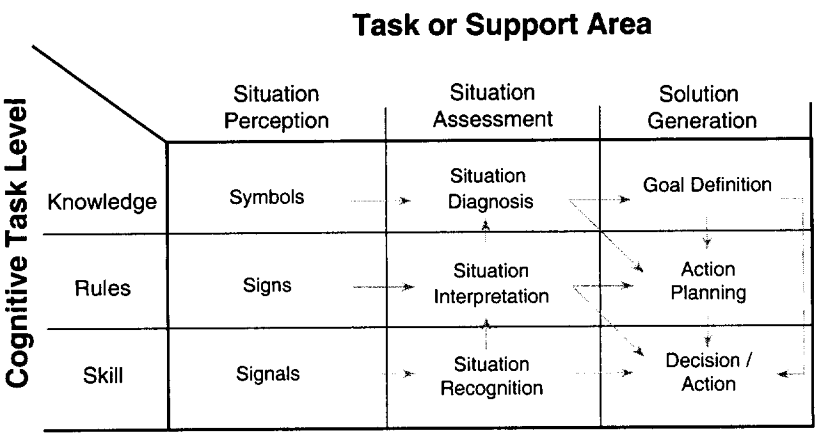

Figure 2: Concept structure of human problem-solving activities

preparation, and operator guidance for information entering to execute tasks.

To establish such a general model, complex operator tasks are divided into three different performance phases according to the normal approach of operator problem solving behavior: (1) situation perception, (2) situation/problem assessment, and (3) solution generation. Additionally to structuring problem solving tasks horizontally into phases, a vertical structure seems to be appropriate for each of the three performance phases. This vertical structure is related to the specific types of situations with different cognitive complexity one has to cope with in natural settings. For this structure the conceptual model of Rasmussen [1983] for skill-, rule-, and knowledge-based operator behavior in performing complex tasks can be adapted as a framework. The resulting concept takes into account the different situations which arise, for instance, in novel military scenarios, i.e., routine, familiar, and unfamiliar situations. The hierarchical differentiation dependent on situational familiarity, expertise, and cognitive operator demand corresponds also to the steps of mental activity which Lim et al. [1996] applied for describing human-computer interactions. This model contains the following steps: perception, interpretation, evaluation, goals and intention, action specification, and execution. Combining the hierarchical differentiation of the three performance phases of problem-solving tasks with the cognitive steps of the model of Lim et al. a conceptual framework has been developed that describes the problem space of human decision-making and problem-solving in complex naturalistic situations with a 3 x 3 matrix (Fig. 2).

On the lowest level of this framework skill-based behavior corresponds to nearly unconsciously and automatic information processing in routine situations or under time pressure and to executing tasks at an reactive level (Fig. 1). On the second level rule-based behavior corresponds to stereotyped information processing in well-known situations at an tactical level or holistic style. On the upper level knowledge-based behavior corresponds to a conscious, controlled, and analytical problem solving using situation analysis and evaluation as well as planning and decision making activities.

Applying the hierarchical structure of human problem solving activities to a realistic problem situation, the following steps of information processing, i.e., situation perception, situation assessment, and solution generation can be identified:

- information, i.e., states from environmental objects, the technical system or the operator behavior is perceived and monitored by a situation assessment process. Relevant status changes, i.e., events are detected and the related information processed. The result leads directly to a reflexive action by the decision/action step of the solution generation process if the information belongs to a well known and recognized routine situation.
- if the available information does not directly lead to a reflexive situation/reaction routine the situation assessment process has to interpret the available information using known heuristics, i.e., using already existing hypotheses about the familiar situation, to come to a situation interpretation. The result of this interpretation will be used by the action planning step of the solution generation process to decide about the appropriate reaction or to plan the appropriate course of actions, if necessary.
- if the information is ambiguous or uncertain and the situation is unfamiliar or ill structured so that the situation assessment process is unable to directly recognize or interpret the situation by known rules, a situation diagnosis has to be performed. On the basis of the diagnosis a course of actions will be identified by the action planning step of the solution generation process if the result of the diagnosis corresponds to the predefined goal. Otherwise, a new goal and the corresponding action sequence for achieving it has to be determined by the solution generation process. This decision depends on the complexity of the hypothesis determined by the situation assessment process.

3 Concept for a knowledge-based operator support

To support the human operator in SA and decision making with complex systems in naturalistic situations adaptive aiding concepts have been developed [Rouse et al., 1988; Rouse, 1991]. These concepts have been developed to overcome human deficiencies in information perception and processing. They have actually been applied as aids for aircraft pilots as a so-called "pilot's associate" [Rouse et al., 1990; Amalberti et al., 1992; Wittig, et al., 1992)]. The basic idea of these concepts is that an overall automation must not be the objective of system development [Bainbridge, 1987]. The human operator should be involved in the decision making process as far as his abilities and his performance are sufficient for achieving mission goals. An aid is provided only to enhance human abilities (e.g. in detecting and evaluating complex patterns or reacting on unforeseen events) and to overcome human deficiencies (e.g. when doing mathematical calculations), i.e., to complement individual human performances.

3.1 Concept of a Knowledge-Based Assistant

For the reasons mentioned, the concept of human-centered automation recommends a computerized assistant that complements the operator like a human partner. The human user is engaged in a cooperative process in which human and computer assistant both initiate communication, monitor events and perform tasks. The computer assistant does not act as an interface or layer between the user and the command system. In fact, the most successful assistant systems are those that do not prohibit the user from taking actions and fulfilling tasks personally, i.e., behaving as a personal assistant that cooperates with the user on the same task. Thus, in parallel to the human operator, the assistant monitors the situation (e.g. states of the system and the environment) and, additionally, operator actions. If the assistant discovers critical situations or inappropriate operator behavior, it may automatically perform some operator-related functions. Faulty behavior of the operator will be classified, announced, and if there is no reaction from the operator, possibly compensated by the assistant. But in any case the user is able to bypass the assistant, so that the responsibility and ultimate decision remains with the human operator.

The knowledge-based user interface [Berheide et al., 1995] to support human operators consists of a knowledge-based user assistant (KBUA) and an interactive multimedia user interface (Fig. 3). Information presentation and the user dialog with the C3 system are accomplished via the user interface which acts as the communication tool for the user with assistant and C3 system.

The knowledge-based user assistant is not an automation or expert system in the conventional sense but contains the knowledge of domain experts and makes it available on the user interface to assist the human operator, e.g., according to situation, mission, task, system states, or operator needs. This aiding or assistance will be attained by a situation- and task-related information presentation and information processing, as well as by means of operator action guidance according to situation relevant tasks and course of actions combined with information input.

3.2 Functional Structure of the Knowledge-Based User Assistant

The functional structure of the KBUA itself consists of three components, i.e., a situation monitor, a solution generator, and an information manager (Fig. 4), representing the three different areas of the general task performance or support structure: (2) situation/problem assessment, (3) solution generation, and (1) situation

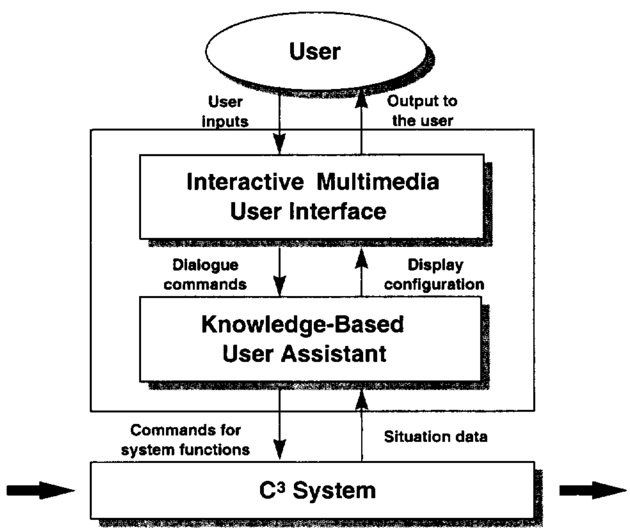

Figure 3: Concept of a knowledge-based user interface

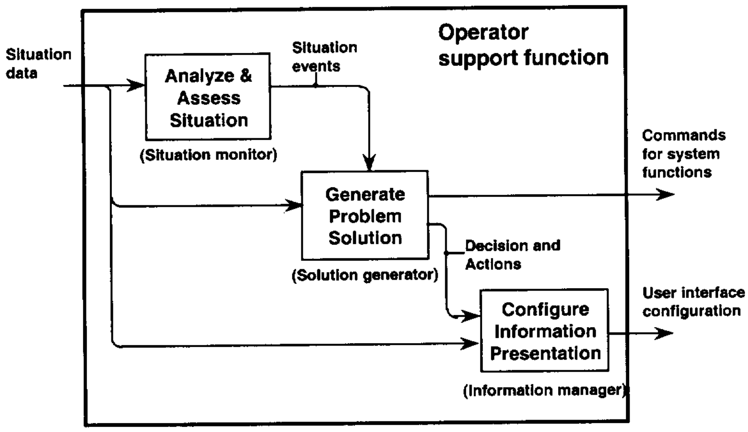

Figure 4: Functional structure of the knowledge-based user assistant

perception/information presentation [Dörfel et al., 1997].

The *situation monitor* supports the operator in gathering information and assessing situations by means of reviewing and analyzing situational data with regard to relevant situational events. The situation monitor itself consist of three different parts monitoring the external situation, the overall system status, and the operator behavior by means of predefined filter functions. The present implementation of this monitor contains only filter functions to monitor the external situation. Later on it will contain functions to monitor system status and operator actions, too.

Problem- and task-relevant situation assessment by the situation monitor is the basis for the *solution generator* to define goals, plan actions to reach newly defined goals or predefined objectives, and generate appropriate decision proposals. Dependent on situation assessment and the time available the planning part of the solution generator decides about function allocation between human operator and machine system components, i.e., "which function" to be accomplished "by whom" and "when", as well as about the information and action requirements of the human operator, i.e., "what" information or action possibility to provide and "when".

Necessary information as well as required action possibilities are presented on the user interface by means of the *information manager*, supporting the information perception process of the human operator by deciding "how" the presentation should be designed and performed.

This general concept of the knowledge-based assistant can be applied to different problem areas as well as to different kinds of operator support. However, specific problem areas require establishing domain-specific contents for data and knowledge bases as well as availability of problem-specific reasoning and problem solving processes, like rule-based or case-based reasoning, diagnosis, and handling of uncertainty by probabilistic reasoning or belief networks. Using the proposed 3 x 3 matrix of problem solving performance (Fig. 2), as an orientation already existing solution systems for restrictively supporting reactive, planning, or decision making tasks can be identified and integrated advantageously into a new support concept. In this way, the matrix structure with its elements allows a modular development and a stepwise implementation of a knowledge-based support concept. This enables developers to quickly react on situational demands.

4 Application of the Proposed Concepts

To demonstrate the applicability of the described KBUA concept for efficiently supporting military decision makers in complex situations demonstrator systems have been prototypically developed for exemplary tasks. In the following one application will be presented in some detail.

In a research project for the German Navy the concept of a knowledge-based user interface has been applied to develop an aid for the Identification/Recognition (ID/REC) process in ship air defense [Dörfel et al., 1999]. The special support concept consists of a number of support functions for an event-related information and task management to efficiently perform the identification process.

The development started with the specification of a realistic crisis reaction scenario. On the basis of this scenario the following operator tasks have been identified for support: a) monitoring the established air picture to detect specific task relevant events, b) identifying newly detected tracks, c) changing the identity of already identified tracks if necessary, and d) performing the investigate procedure for SUSPECT or HOSTILE tracks showing threat relevant behavior.

In cooperation with naval experts a limited number of exemplary criteria have been defined from the scenario and assigned to ID states of a track. From these criteria an event list has been deduced to define ID state transitions caused by situational events. Fig. 5 shows the corresponding state transition diagram of a track comprising ID states, exemplary situational events, and

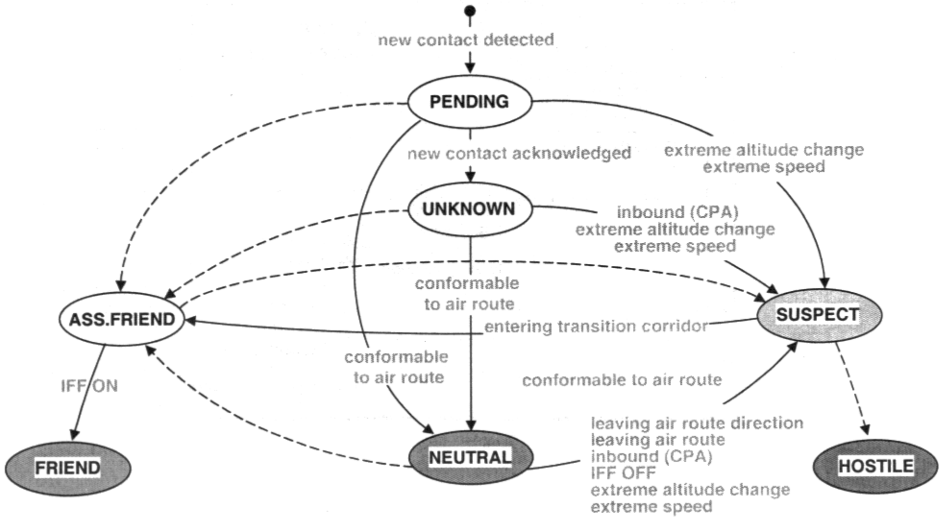

Figure 5: ID state transition diagram for exemplary events

related state transitions. This diagram has been used for developing the logic of the situation monitor, the functions of the solution generator, and the user interface configurations applied by the information manager.

The ID/REC process has been supported by presenting actual data as well as preprocessed situational and task relevant information on an interactive graphical user interface. Additionally, the operator has been guided by providing information entering possibilities on this interface (Fig. 6).

Each task-relevant situational event will be notified at the user interface by presenting a virtual event/action button (VEAB) and a related information/action window. The VEABs are prompts or warnings about the occurrence of task-relevant events or calls on performance of special tasks for related tracks, respectively. Additionally, they present important information about those tracks. The VEABs are arranged by priority where VEABs for critical events or tasks with a high performance priority are placed most left. After confirming a notified event or accomplishing a task called for the related VEAB will be deleted.

Activating a VEAB will open the related information/action window (IAW) for the specific track. Track number and specific icon as well as type and class of the track are presented. Situation perception as well as situation assessment are supported by the presentation of actual track attribute values and preprocessed information like trend information, min/max values of

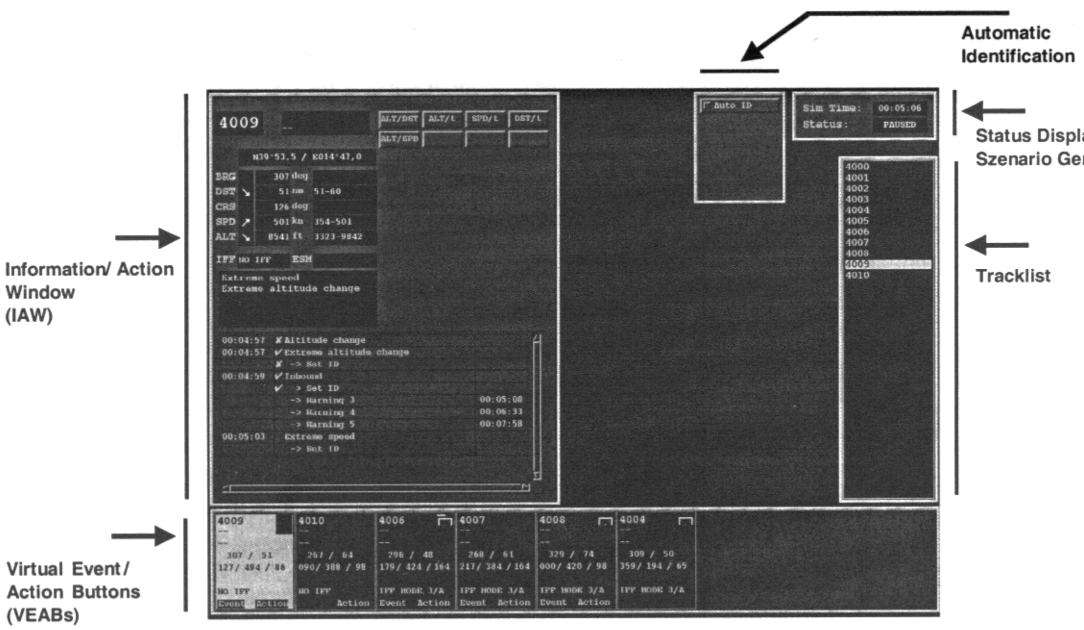

Figure 6: Graphical interactive user interface for ID/REC

the kinematic track data during the observation period, histories of speed, altitude, and distance as well as relations of altitude versus distance or speed. Besides these quantitative information additional qualitative information is presented textually. The sum of this information serves as an exhaustive operator support in situation/problem awareness.

Additional support for situation perception and assessment as well as for decision making and task performance is given by the presentation of task relevant events and related actions in an event/action list. This list contains events occurred combined with relevant action proposals in a chronological order. Selecting a special event from the list will show additional information characterizing and explaining that event. Selecting a proposed action from the list will show additional information related to the causing event as well as a decision or action suggestion with explanation for that special suggestion. These decision/action suggestions together with the presentation of alternatives support the solution generation of human operators.

In action execution the human operator is supported in the way that he is able to directly confirm the system's suggestion, choose and execute an proposed decision/action alternative or delete the decision/action suggestion. Additionally, the execution of actions consisting of an activity sequence is supported by the presentation of a time-line of the activities to be performed as well as of specific alerts to perform these activities optimally in time and distance or space.

Besides the situation-relevant information presented automatically by the support system there is the possibility to present additional preprocessed information on operator demand. This are histories of the kinematic data altitude, distance, and speed as well as relations between these values.

For operator relief there is the possibility on operator demand to automatically identify tracks fulfilling predefined criteria like, e.g., flying en route an air lane and emitting a civil IFF code.

5 Summary and Conclusion

Difficulties of human operators performing demanding problem solving tasks in natural settings have given rise to the need for support systems that can assist them in assessing and reacting to complex and rapidly changing situations. Obviously, problem solving tasks in such situations, especially military situations, may be supported by knowledge-based systems. At present it may not yet be possible to design a system addressing all possible events in highly ambiguous situations, such as those found, for instance, in military crisis reaction operations or operations other than war. But it is already possible to develop support systems that complement human's ability in perceiving such situations and in responding appropriately in novel situations. The concepts presented in this paper provide a systematic approach for the design of knowledge-based systems to support problem solving in complex situations. The basis of the approach is a generic description and framework of the human problem solving process itself.

The knowledge-based user assistant system developed and implemented for supporting decision making and action taking in naval air defense situations demonstrates the potential of such an approach. With the developed interface demonstrator, the advantages of this concept for operator support in complex problem situations like identification/recognition (ID/REC) could be shown.

The information presentation provides the decision makers with needed information, thus supporting all three levels of SA: perception, comprehension, and projection in the tactical and operational area. The information is displayed corresponding to the task-relevant operator needs, i.e., he can easily perceive and use the information without undue cognitive effort. Thus, operator workload is reduced because the information corresponds directly to his task goal, i.e., for identification of air targets to encounter possible threats in air defense.

In addition to SA support through prompts and warnings operators are alerted to task-relevant events and prompted to the appropriate actions by specific proposals and by guidance for action sequences. In addition to situation awareness, this improves decision making and action command. However, the ultimate decision remains with the human operator himself, thus, keeping him as an integral and critical part in the decision loop.

The knowledge-based user interface concept developed is a very general one and can be applied to different kinds of operator support systems for a variety of different missions and tasks. Human operators will be supported by information presentation and user guidance which are adapted to mission, situation, task, system status, as well as to operator abilities. For the development of the demonstrator an object-oriented approach and a modular architecture have been applied that allow changes and extensions of the demonstrator to be made easily. Therefore new as well as additional functions can be integrated quickly.

The concept of the knowledge-based user interface consisting of a knowledge-based user assistant (KBUA) and a multi-media user interface will be further developed. It is actually adopted for developing a support system to aid the CIC team in developing and using doctrines for automatically controlling the combat direction system of a German Navy frigate.

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DIRECT MANIPULATION INTERFACE TECHNIQUES FOR USERS INTERACTING WITH SOFTWARE AGENTS

Michael Young
&
Robert G. Eggleston
Air Force Research Laboratory
Human Effectiveness Directorate
2698 G Street
Wright-Patterson Air Force Base, OH 45433
USA

&

Randall Whitaker
Logicon Technical Services, Inc.
PO Box 317258
Dayton OH 45437-7258

Summary

In this paper we provide an overview of our research investigating what functionality should be provided to users of a future *Joint Battlespace Infosphere (JBI)*. We characterize and discuss the development of the JBI as a new form of automation that employs intelligent agents to autonomously seek, retrieve, and fuse information . We believe that the development of new types of direct manipulation interfaces are the best approach to achieving JBI goals of reducing decision time and manning while maintaining positive control over the command and control (C2) system. Further, we argue that the integration of direct manipulation interface techniques with interface agents will change the HCI from a mechanism to execute tasks into a decision-aid that supports cognitive information processing. We contextualize this discussion by providing an overview of the Air Force Research Laboratory's Human Interaction with Software Agents (HISA) project. This effort is developing a HCI for Air Mobility Command's (AMC) Tanker Airlift Control Center (TACC) that interacts with operational C2 systems through intelligent agents, similar to the manner of the proposed JBI.

I. The Joint Battlespace Infosphere Concept (JBI) as a Three-Layer Model

To achieve the goal of information dominance on the battlefield, the U.S. Air Force is exploring the development of a *Joint Battlespace Infosphere (JBI)*. The JBI is proposed as an integrated C2 system encompassing the entirety of Air Force operations. The JBI will be implemented through data and communications networks which will enable warfighters to plug into the JBI in a fashion analogous to logging onto the Internet. The JBI will then provide these warfighters access to the complete range of information products and services necessary for operational decision making. As a comprehensive decision making environment, the JBI would serve as both the repository and generator of mission critical data. Individual warfighters would provide data for the JBI and in turn receive fused presentations of information tailored to their goals and needs.

Two of the primary goals of the JBI concept are the reduction of warfighter decision times and staffing demands. The first goal is to be obtained by more efficiently accessing and fusing decision-critical data and more effectively presenting it for employment in decision making tasks. The second goal is to be obtained by eliminating inefficiencies and redundancies in the current 'stove-piped' information architectures among numerous operational units. Both goals can be obtained to the extent the cognitive burdens of decision makers are reduced. Reducing decision makers' cognitive burdens serves the first goal by facilitating the decision processes of any given decision maker. It serves the second goal by leveraging decision making efficiency to permit smaller staffs to equal or exceed current performance standards.

Implementation of the JBI requires translating the concept into deployable decision support tools and systems. Our analysis of the JBI concept suggests that the requisite network-oriented deployable products will evidence three types of functionality, which in turn can be described in terms of three layers:

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- A *network services layer* which provides connectivity between the various C2 systems;
- an *application services layer (ASL)* which provides services such as planning, scheduling, and information fusion, often mediated through intelligent agents; and
- a *human computer interface (HCI)* layer through which warfighters receive information and enact operational tasks.

II. Agent Support Criteria for the HCI and ASL Layers

The primary areas for intelligent agent support will be the ASL and HCI layers, and it will be these two layers upon which our discussion will focus. It is important to clearly distinguish between these two layers, primarily because their respective implementations will employ intelligent agents, albeit quite differently (Milewski & Lewis, 1997). Although both involve multiple processes (i.e., agents) communicating with one another in an intelligent fashion, our project experience suggests it is critical to 'frame' the purpose of these layers in distinct ways. This 'framing' allows for more precise identification of agents' roles, as well as illuminating the optimum referential context for design and implementation of agent support, for each layer.

To illustrate, in the following paragraphs we shall summarize the ASL and HCI layers with respect to three critical dimensions of agent implementation:

- *ontology* – the fundamental semantics underlying terms of reference and types of inference.
- *homo-/heterogeneity* – the differential unity / multiplicity of elements (or element types) engaged by users, the agents, or both.
- *autonomy* – the degree to which a given agent (or class of agents) functions outside the scope of user monitoring and/or direction.

II.A. The ASL Layer

The ASL is best characterized as a functional architecture designed to accomplish specific tasks such as scheduling aircraft and crews for specific missions or planning the movement of forces into a theater of operations. Given the diversity in both legacy and prospective mission-critical systems, the ASL must provide for a flexible mapping of tasks to computers (or computer processes). In a traditional C2 system a task (e.g., scheduling) is often accomplished by a specific computer running a specific (scheduling) application program. In contrast, in the JBI tasks will not be mapped to specific hardware / software platforms. Agents working for a specific user will request a service, and other agents will manage the details of how and where that service is actually accomplished (e.g., on which computer; using which software). This illustrates two important points. First, the 'ontology' for ASL agents must emphasize procedural logic, support systems, data routing protocols, etc. Second, the multiplicity of items (and item types) referenced in this ASL ontology means that heterogeneity of functionalities (and loci of functionalities) will be a key concern in ASL design and implementation.

This heterogeneity extends to the agents themselves. That is, the ASL layer will not exhibit a single standard language, type of agent, or form of agent communication. Instead, there will be a variety of agents that speak a diversity of languages (e.g., Knowledge Query Mark-up Language [KQML] {Finn, Labrou, & Mayfield, 1997}, Knowledgeable Agent-oriented System [KaoS]{Bradshaw, Deutfield, Benoit, & Wolley, 1997}) and employ a number of communication protocols. This conglomerate of distributed disparate agents will advertise and broker services among themselves in order to find the optimal means to complete a specific task in the operational context of priorities, situational constraints, and other related tasks underway.

Agents' 'brokerage' of diverse goals, tasks, conditions, and functionalities will add value to the extent that it manages the relevant complexity (i.e., complexity of type – heterogeneity) on behalf of (e.g.) planners and commanders. In this case, the obvious tactic for complexity management is to allow the agents to automatically handle the details of user-defined tasks. Phrased another way, ASL agents' value will be directly proportional to the amount of detailed tasking they can accomplish without users' direct inspection and guidance. As such, the hallmark of useful ASL agents is capacity for autonomous action (vis a vis the user).

II.B. The HCI Layer

In contrast, the HCI layer is defined with respect to the user him/herself. In a traditional C2 system, most tasks are initiated and managed by a user. In contrast, design goals for the JBI include reducing the decision-making cycle time, while simultaneously reducing the number of personnel, and while maintaining positive (human) control over the weapon systems. The HCI layer, then, must provide the capacity for user inspection of task parameters as well as the means through which the user invokes and manages his/her tasks. In contrast to the ASL layer, the HCI layer is best characterized as an architecture of forms (as opposed to functions) designed to facilitate understanding of and control over specific tasks. More specifically, it is implemented as a collection of graphical user interface [GUI] widgets that actualize a user-interface model in which the user delegates to and collaborates with intelligent software agents.

The HCI layer is effective to the extent it facilitates non-autonomous actions – i.e., those actions reserved for direct human control. This fact underlies one critical distinction between design approaches to the ASL and HCI layers. In the ASL layer, the opportunity for agent autonomy affords designers the ability to design with respect to any functionalities the software agents can implement. In the HCI layer, the requirement for discretionary user control (i.e., HCI agent non-autonomy) forces designers to constrain themselves to prioritizing those particular functionalities the human can and/or must manage.

The most obvious thing the human must manage is his / her interactivity with the HCI layer itself. As the primary point of engagement between user and system, the HCI layer is the explicit 'point of service' for the JBI. For the JBI to support effective work and decision aiding, the HCI layer must itself be designed as an effective work / decision aid. This means that the HCI layer must be designed so as to reflect key referential and operational aspects of the task and related decision space(s). As such, the HCI layer must be based on an ontology consistent with the user's viewpoint – i.e., an ontology focusing upon the mission, specific tasks, and decisions.

The kind of diversity (heterogeneity) that is usefully exploitable in the ASL layer is itself a serious problem for humans to routinely handle. The user's cognitive workload should not be increased by forcing him/her to deal with details of the HCI layer's implementation – e.g., the specifics of how the HCI agents interact with the ASL agents. This means the HCI layer must emphasize both simplicity (non-complexity) and consistency of both form and function in portraying and addressing tasks, conditions, tools, and functionalities. As such, homogeneity must rule in any HCI. That is, a user must be able to rely upon a GUI widget coherently displaying task parameters and consistently performing any functions he/she invokes in response. If a widget displays the status of an airbase in one fashion at one time, the user should expect it to portray that status in the same fashion (a) for other airbases anytime and/or (b) that same airbase some other time. Similarly, if a widget allows specific actions (e.g., drilldown to more detailed status data) on one occasion, the same functionality should be predictable the next time the widget is used.

II.C. Summary of ASL / HCI Design Tradeoffs

Figure 1 is offered as a summary illustration of these points. The 'squares' represent interface elements visible to the user, and the 'spheres' represent the software agents servicing the interface as well as accomplishing the ASL layer functions.

At the interface, the HCI layer offers specific functionality (e.g., scheduling missions, requesting resupply, etc.). The user may not know (or care) that the functionality being provided is mediated through interface agents (the spheres clustered behind each interface element). He/she may not know because the interface reflects a task-oriented (as opposed to a system-

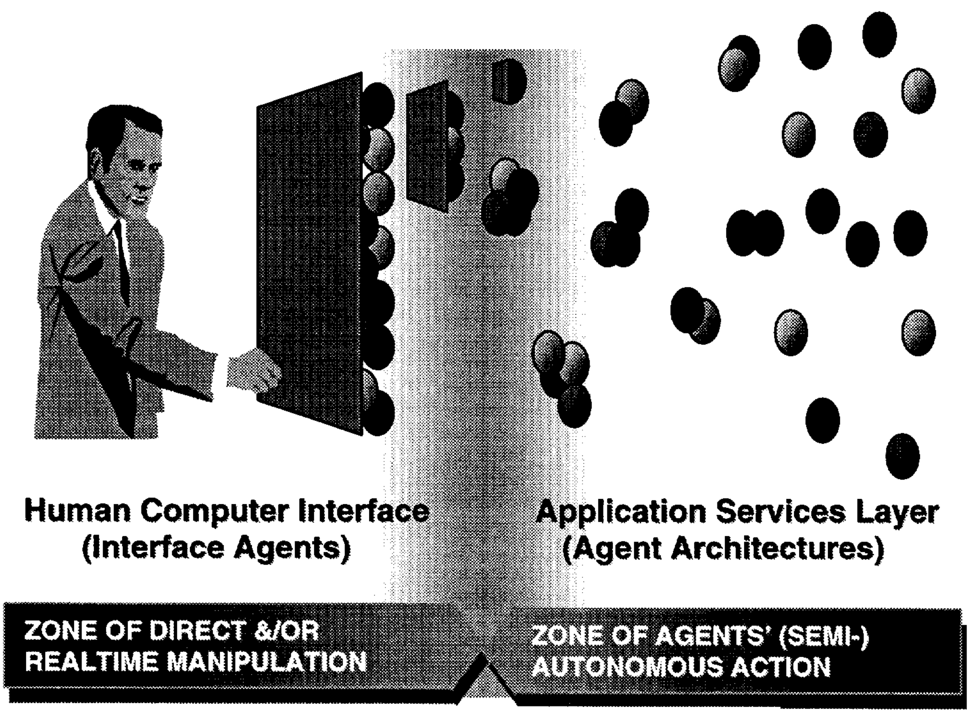

Figure 1: The HCI and ASL layers

oriented) ontology. He/she may not be aware that as we move farther into the ASL layer, agents increasingly interact autonomously among themselves, brokering services and accomplishing tasks. Conversely, as we move in the other direction (from ASL toward HCI), agents (and/or agent sets) increasingly reflect task-oriented factors, and may be provided interface elements by which the user can address them directly (e.g., setting functional preferences).

In between the extremes of the ASL and HCI deployment styles is the gray area depicted in Figure 1. This is the domain where the homogenous HCI layer's agents interact with the heterogeneous agent-based ASL architectures. It is also the point at which full agent autonomy comes into play. Because it represents the extent of HCI service 'coverage', this middle ground demarcates the user's zone of awareness with respect to the JBI. On the one hand, it is from this point rightward (cf. Figure 1) that autonomous agents can be trusted to operate out of sight of the user. On the other hand, it is from this point leftward that agents are usefully made 'visible' for user inspection and 'available' for user manipulation. For example, users may want to "drill-down" into this area to tailor agent behavior – e.g., selecting a specific module for a particular task or creating new agents to serve as sentinels for problematical conditions. As such, it is in this middle ground that tradeoffs must be determined involving our two critical factors of homo-/heterogeneity and autonomy.

Perhaps even more importantly, this middle ground is the point at which the ASL and HCI layers' ontologies must intersect and interoperate. With respect to Figure 1, it is from this point rightward that the ASL layer's system-oriented ontology may prevail, and it is from this point leftward that the HCI layer's task-oriented ontology must prevail. For the above-cited drill down to be effective, there must be semantic interoperability between the users' conceptual work domain model (via the analogous HCI layer task ontology) and the ontologies of the ASL agents brokering services among planners, schedulers, search engines, etc.

The most difficult challenges facing JBI developers concern interoperability tradeoffs between the HCI and ASL layers as described above. They must provide for interoperability between the users' homogenous interface and the heterogeneous agent world. This functional interoperability must be qualified with respect to reasonable allocation of users' control versus agent autonomy. Finally, the distinct semantic priorities of the ASL and HCI layers must be interwoven through interoperability of their respective ontologies. These difficult goals must be achieved in a manner that (a) maximizes functionality provided the users; (b) minimizes users' cognitive workload; (c) maximizes system operational efficiency; and (d) promotes task effectiveness in JBI applications.

III. Our Work-Centered Interface Concept

In this section we review some of the design goals we hope to achieve by creating a separate HCI layer, where the user's interaction with the system is mediated through interface agents. First, we outline what we see as the primary problem – cognitive burdens on the decision maker entailed in addressing two distinct ontologies (domains of reference and knowledge). Second, we identify two major design goals for alleviating this problem. Finally, we present the HISA design criteria through which we pursued these design goals.

III.A. The Problem: Complexity of Ontological Reference in User / System Interaction

In general, every computer-implemented decision aid can be differentiated into two distinct functional components:

- The *decision-making component* supports task-specific decision making (e.g., deconflicting an aircraft scheduling problem.). The decision-making component must be configured so as to allow the user to address the task he/she is executing.

- The *information manipulation component* supports task-specific data / information activities (e.g., accessing a system to retrieve data or to assign a new mission start time. The information manipulation component must be configured so as to allow the user to address the tools (information systems) he/she employs in the course of the task.

Owing to this dichotomy of reference, these two decision aid components differ in the types of knowledge that must be active. A decision-making task requires activation of a *task domain ontology* – i.e., the set of specialized terms, meanings and relations between terms that captures or represents the subject matter itself (i.e., the domain knowledge of scheduling goals and constraints). Information manipulation requires activation of a *system ontology* – i.e., the set of specialized terms, meanings and relations between terms that captures or represents working knowledge of the subject matter documentation.

Consequently, a user engaged in decision-making must engage in multi-tasking behavior which involves (potentially extensive) shifting between the frames of references (or activate ontologies) of the systems and task. Let us illustrate this with an example. To deconflict a scheduling clash, a mission planner may have to access two or more systems. Interacting with each system requires the planner to develop and execute an information manipulation strategy. This may require several procedural steps such as logging on to a system, accessing the appropriate data base, and then executing a query. Phrased another way, the user must generate and work through a plan distinct from, but potentially of similar complexity as, the mission plans involved in the scheduling clash. In utilizing the retrieved data for deconfliction, the planner must then turn to an entirely separate referential framework reflecting (e.g.) aircraft, airfields, and planning constraints. In other words, the planner must invoke and refer to a referential set distinct from, but potentially of similar complexity as, the data dictionaries underlying the retrieved data.

The user must therefore grapple with developing a single problem solution via engagement with two distinct referential and procedural frameworks. This increases the user's work demands, cognitive burdens, and risk of error. With respect to our deconfliction example, the user encounters transcription costs in assembling relevant data from multiple sources (e.g., writing down or printing out conflicted missions' data as it comes in). Once all the relevant data is at hand, the user must then endure the interpretation costs for interrelating a set of data field entries and a set of mission arrivals / departures at the given airfield.

III.B. The Solution: Minimizing Ontological Complexities to Reduce User Cognitive Complexity

The above-cited costs are a matter of *cognitive complexity*. Cognitive complexity (Chechile, Eggleston, Fleischman, & Sasseville, 1989) is a measure of how much cognitive resources are required to execute an activity. Note that cognitive complexity for an activity is an aggregate of complexity of the information manipulation and decision-making components. Cognitive complexity for an information manipulation task is usually a function of how much planning is required to execute a task. Cognitive complexity for a decision-making task is harder to quantify because of the variability of the types of tasks the actor is engaged in and the role the actor's skill level plays in task performance.

This dilemma would be minimized to the extent the system and task ontologies correspond (e.g., in terminology). Unfortunately, this correspondence is rarely evident in management information systems. Moreover, the increasingly integrated network character of emerging command and control architectures are predicated upon the ability of warfighters to 'drill down' (into their own data assets) and 'reach back' (for data assets possessed by someone else). Because the trend is toward increased referential qualifications (drill down) or more numerous data sources (reachback), the above-cited ontological dilemma can only become more problematical.

Much of the HISA interface design effort was directed toward enhancing task / system correspondence and reducing mission planners' current reliance on work-around strategies and tools (e.g., pen and paper). Our design goals for the agent-based HCI layer focused upon providing mission planners with more direct support for their decision-making through:

- increasing the time the user operates "on-task" – i.e., accomplishes task activities by working with reference to the task domain.
- reducing the amount of time the user digresses "off-task" – i.e., is sidetracked into activities requiring reference to the system domain.

III.C. Our Approach: A 'Work Centered' Interface Style

The two key solution criteria cited above must be reflected in design and development work to obtain the expected payoffs. To accomplish this, we translated the goals and principles cited above into a set of HISA interface design criteria to guide our work. These criteria reflect the following priorities:

- maximize explicit reference to task domain elements in the on-screen HISA information displays
- maximize cross-reference among HISA information displays with respect to core task domain concepts (e.g., missions, airfields, courses of action)
- minimize procedural costs for accessing and retrieving relevant data (e.g., by automating queries)
- maximize effective fusion of data from the multiple databases with which the planners must currently interact (e.g., by assembling a single airfield summary view from data scattered across numerous database tables)
- minimize cognitive burdens for identifying, seeking, and/or interpreting relevant information (e.g., by reducing interpretational demands)

The implementation strategy uniting the above-cited design goals and approaches entailed a trade-off between (a) the interfaces engaged by the users and (b) the functionalities delegated to the software agents. We strove to configure the display components to prioritize task domain referentiality, and we prioritized allocating system domain-oriented actions (e.g., database access) to the agents.

This is not simply a matter of providing a highly graphical direct manipulation user interface. Direct manipulation capabilities do help reduce the cognitive complexity of the information manipulation component by making it easier to directly manipulate information elements. In the eventual realization of the JBI concept, warfighters must access multiple systems, each one of which may provide a very different interface. Direct manipulation, accordingly, does not necessarily eliminate the need to switch ontologies. As a result, direct manipulation alone is not sufficient to accomplish our design criteria and hence our design goals.

Interface concepts can be characterized with respect to either the perspective of the user (e.g., direct manipulation) or the perspective of the system(s) (e.g., object oriented, agent-based). We believe the key innovations of our HISA effort, though involving novel system capabilities, are best characterized from the user perspective. Though the HISA interface elements (as viewed by the user) certainly represent 'direct manipulation', this label does not convey what we see as the really innovative aspect of this work. Our HISA interface concepts direct as much of this direct manipulation as possible to task (as opposed to system) elements.

In other words, we are attempting to more directly support task decision-making by effecting a closer correspondence between on-screen display elements and elements of the task domain (as opposed to elements of the information space). In effect, we are making the system more 'transparent' vis a vis the mission planners' tasks. This strategy reduces the cognitive complexity involved in addressing task activities by reducing the procedural and interpretational overhead for addressing task issues through the 'lens' of support system-specific interfaces. This allows us to maximize the time the user spends oriented to the task domain itself by maximizing his/her ability to address task activities in terms of task (as opposed to system) ontology. We call an interface which realizes our design criteria *work centered.*

IV. Our HISA Products as Work Centered Interfaces

The Air Force Research Laboratory (AFRL) has been researching work centered interfaces as part of the "Human Interaction with Software Agents" (HISA) project. The target worksite for HISA products is the Tanker Airlift Command Center (TACC) – a mission planning and execution center within the USAF Air Mobility Command (AMC). TACC units plan, schedule, and monitor airlift missions on a continuous basis. More particularly, HISA has concentrated on the specific category of *channel missions* – those missions which are routinely conducted along established routes. Key characteristics of the USAF channel mission planning work include:

- *Long lead times for mission plans.* Channel mission plans are typically drafted and published months ahead of time (in advance of mission take-off) to enable organizations to plan family moves.
- *Heterogeneous data assets.* Missions are initially planned using one system, with the final version being 'published' to another. These system differ in the way the data tables are laid out. Further, multiple other databases each uniquely contain relevant information such as (e.g.) airfield restrictions and alerts on airfield status.
- *High cognitive burden for data access.* The multiplicity and diversity of record tables make it laborious to track down specific details of a mission. When obtaining such details require access to multiple tables and/or other databases, planners must execute multiple queries – potentially involving multiple search syntaxes.
- *No capacity for unified issue visualization.* The scheduling system provides only structured textual records of mission data, arranged by mission. To review issues involving multiple missions, planners must often execute a query, print out the results, and review this printout manually. Discerning on-ground conflicts at a given airfield typically requires interrelating mission text entries by drawing lines among them with a pen.
- *Little or no automated decision support.* The system provides no automated inference to detect conflicts among mission plans as they are accreted. Moreover, the system provides no automated alerts on conflicts and other problematical conditions.
- *Discontinuous situation awareness.* Once a channel mission is published (months ahead of time), conflicts resulting from subsequently-published missions can go undetected (and hence unresolved) until it is nearly time to launch the mission.
- *High potential for time-critical problem solving under duress.* In accordance with TACC business rules and policies, channel planners must usually defer to planners of other missions types (e.g., contingency missions) when resources (e.g., aircraft) are insufficient to execute all plans at once. The above-cited conditions make for frequent last-minute replanning problems, while the channel missions' low prioritization diminishes planners' ability to definitively resolve those problems on their sole initiative.

As of the time of this writing, the HISA effort had produced design specifications for a work-oriented planner interface, as well as dynamic demonstration models for some core elements of this interface. Our HISA interface elements have been demonstrated in real-time interoperability with networked data sources, providing concise and coherent displays of mission planning parameters as well as offering proactive support (e.g., alerts; plan conflict data) for decision makers. The following sections offer selected examples of our HISA interface elements and illustrate how they both (a) address problems faced by the client TACC channel mission planners and (b) illustrate the principles, goals, and criteria outlined earlier in this paper.

IV.A. The Foundation for Work-Oriented Interface Design: A Task Ontology

Agent-based support will afford us the ability to shift the users' 'field of vision' from the machine to the task itself. The 'intelligence' of ASL and HCI agents will relieve users of cognitive burdens attributable to having to understand the mechanics of the support system to get a task accomplished. As a result, an agent-based HCI layer allows an unprecedented ability to reflect the ontology of the task rather than the ontology of the system(s). By disengaging the task semantics from the tool semantics, we have been able to design our HISA HCI layer elements to directly reflect the mission parameters comprising the critical issues in the planning process, as opposed to the planning artifacts (e.g., cryptic database records) reflecting the limitations of the planning documentation (Eggleston, 1993).

The first step in accomplishing this required the development of a coherent task ontology which was consistent with the key referential, inferential, and procedural elements by which users engage their work. It was obvious from the start that the primary object of task engagement was the mission plan – e.g., the documented record of a scheduled mission as stored in GDSS. However, it was equally obvious that the problematical issues listed above all related to grappling with this mission plan documentation at the expense of efficiently and effectively addressing the subject matter documented. Our first goal was to identify the key subject matter on the way to configuring the HISA interfaces to reflect it.

The initial knowledge acquisition efforts clearly indicated the primary object of referential and inferential engagement was the mission itself – i.e., the act of employing an aircraft and crew to transport a specific set of items from one airfield to another. We therefore nominated "mission" to be the core construct around which to develop the mission planner task ontology. Further analysis (e.g., of actual and representative problem scenarios) resulted in our subdividing this core construct into three components:

- *Port* – Either one of the airfields involved in a given mission leg.
- *En Route* – The passage of the loaded aircraft from one Port to the other.
- *Package* – The aircraft, crew, load, and other items required to perform a mission leg.

Our early knowledge acquisition indicated that problems were typically delimited with respect to one or another of these components. For example, lack of a functional aircraft was a Package issue. Similarly, weather-motivated diversion to an alternate landing site was an En Route issue, and exceeding the established *Maximum On-Ground (MOG)* limit for a given airfield was a Port issue. This conceptual model allowed the HISA team to create a taxonomy of interface displays reflecting both (a) a logical taxonomy of subcomponents of the core referential construct (i.e., the mission), as well as (b) a reasonable categorization of known task problem features. Identification of the critical data and information necessary to portray each of these subcomponents led to the development of specialized displays (termed "Viewers") for each. One such display (the "Port Viewer") is described in more detail later.

This initial task ontology development set the stage for meeting our design goals of prioritizing "on task" user engagement. More specifically, this effort allowed us to satisfy our design criteria of maximizing explicit reference to task domain elements; maximizing cross-reference among HISA information displays with respect to core task domain concepts; and minimizing cognitive complexity in terms of interpretational demands.

IV.B. Work-Oriented Interface Implementation: The Port Viewer

The best-received of our work-oriented displays is the 'Port Viewer' illustrated below in Figure 2. The Port Viewer is a discrete interface element portraying the arrival and departure of flights for a given airfield for a given 24-hour period. This affords direct graphical summarization of conditions which planners must currently infer from a large text printout. By portraying the on-ground circumstances in one way at one time, we can allow agents to infer and depict problematical conditions (e.g., red highlighting of the period during which too many aircraft are present). In addition to displaying mission-critical information, the Port Viewer provides ready 'drill-down' capabilities via the buttons arrayed to either side of the central display. This allows planners to access additional information (e.g., airfield restrictions, clearance requirements, full data on any mission selected) without having to call up another interface unit to execute additional queries against one or more databases.

The data necessary to achieve this concise overview is currently distributed in numerous record fields among multiple databases. Some of the data required to 'draw a picture' for the user is not stored in accordance with the user's 'semantics' at all, and must be interpreted through inference. The invocation of ASL layer agents allows for this necessary data access, fusion, and interpretation out of sight of the end user. This avoids confusing the user with unnecessary details in the data stream itself, as well as relieving the user of cognitive burdens associated with manipulating the mechanics of the database and/or making sense of the data received.

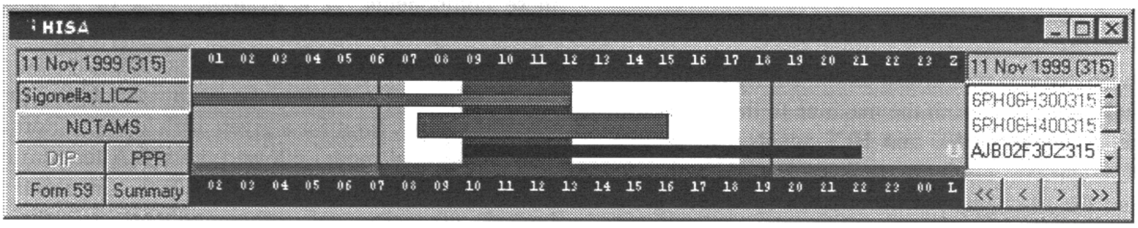

Figure 2: The Port Viewer

To summarize, the Port Viewer provides a unified, fused data display configured to reflect the user's task ontology, absent superfluous details and interpretational cognitive burdens which increase the potential for errors. It affords the user referential homogeneity (simplicity) with respect to data sources of high heterogeneity. It accomplishes this by according agents autonomy to perform the requisite data retrieval and fusion. In addition to satisfying the design criteria listed above for the general task ontology development, the Port Viewer illustrates minimum procedural costs for accessing and retrieving relevant data as well as maximum effective fusion of data from multiple sources.

The Port Viewer concept has received positive feedback and acceptance from the planning personnel to whom it has been demonstrated. The key to this 'payoff' has been our ability to offer HCI layer elements consistent with the ontology of the user's work and not constrained by the ontology of the supporting system(s).

IV.C.. Homogeneity of User Work Engagement: The Smart Lieutenant Palette

The most striking characteristic of channel mission planners' information systems support was its extreme heterogeneity. There was no single 'entry point' into the complexities of the mission planning, problem identification, replanning, and mission execution tasks. Our HISA interface architecture provided such an integrated entry point via the 'Smart Lieutenant' palette illustrated in Figure 3 below.

The Smart Lieutenant palette provides the mission planner with a single display from which he/she can access all other relevant classes of display elements. Records of missions (either specific ones or all missions for this planner) can be invoked. Alerts generated by intelligent ASL agents can be managed through invocation of a pending alert queue or a historical listing of past alert conditions. Indicators on the palette cue the planner to the presence of pending alerts, as well as the arrival of new alerts since he/she last reviewed the alert queue. In a similar fashion, the planner is allowed to manage the stream of incoming queries and reports (automated stock queries), as well as to invoke a Query Assistant to generate new queries. Finally, a set of tool options allow the planner to inspect and/or manipulate agents, contacts, and preferences.

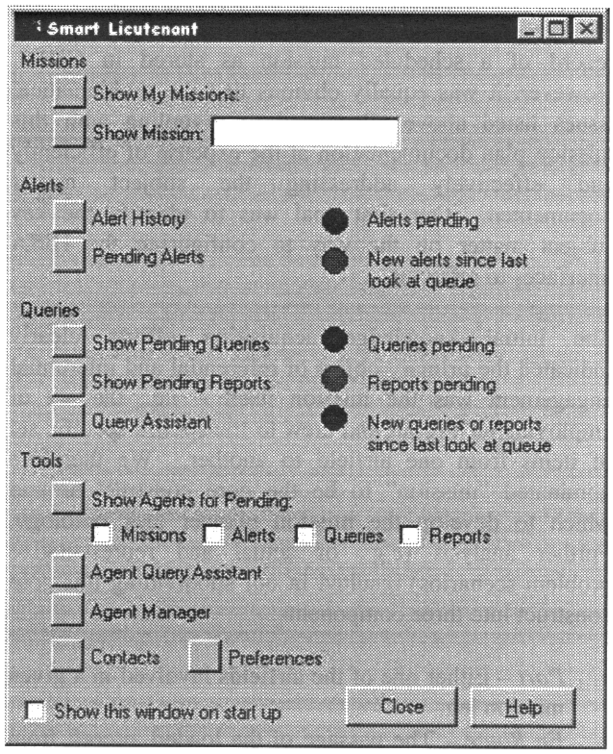

Figure 3: The Smart Lieutenant Palette

The Smart Lieutenant palette enforces referential and procedural homogeneity in the user's engagement with the obvious heterogeneity of his/her support agents and the mission planning information systems. As the top-level procedural portal, this interface element is the one most reflective of system semantics (e.g., queries, agents). However, this invocation of system ontology is The Smart Lieutenant palette reflects our design criterion of maximum cross-reference among HISA elements with respect to the task domain constructs of (e.g.) information requests, pending issues, and workload management parameters. It maximizes effective fusion of procedural data into one concise portal for subsequent drill-down. It minimizes procedural costs by affording direct drill-down to key task elements. It minimizes cognitive complexity by summarizing the existence of alerts, queries, reports, and relevant agents.

V. Conclusion

We began this paper by discussing the command and control system of the future—the JBI—and some of the challenges and opportunities it affords HCI designers. We then discussed the role that interface agents will play in creating an environment that enables a user to remain "on task" longer, and concretized the discussion by providing example interfaces from the HISA effort. In this final section, we discuss the challenges of developing direct manipulation, work centered, interfaces for a full vision JBI. Up to this point, we have characterized the JBI mainly in terms of three different services layers. Our discussion has concentrated on an agent-based direct manipulation interface concept in the context of a distributed network-centric architecture focused on airlift command and control. It is important to recognize, however, that the full vision of a JBI involves a diverse collection of network centric systems that integrate air and space operations. One should ask if the agent-based work centered interface concept can scale to meet information usability needs for a full-blown JBI.

The JBI Information Technology concept consists of a core network system designed from the perspective of supporting battle management activities within an Air Operations Center framework. The principal goal is to enable the Joint Force Component Commander and supporting staff to make well-informed decisions that can be executed rapidly in a highly coordinated manner. Space operations, airlift, logistics, intelligence, and network security are all elements that support contingency operations. Each of these areas of the military organization are represented both in the core JBI system and via links to the extensive information networks maintain in each separate area. The essential idea for the JBI is that a core information/command and control system will be operational to support the commander within hours after approval for a contingency operation. Multiple JBIs may be in commission and operated itself constrained with respect to task-specific features. The alert queue provides a 'to-do list' by which the planner can organize his/her daily itinerary. Similarly, the query features are offered with respect to the planner's work flow and activity history, and agents can be called up based upon their participation in a specific task event (mission display, alert notification). simultaneously, each sharing a common web with links to information and other resources provided by the same support agencies. In some sense, each JBI will be a "virtual" organization pulling on assets from every available source regardless of its physical location.

Clearly the level of information management associated with the JBI concept is unprecedented for military operations. Rather than reducing the "fog of war" it could in fact equally as well contribute to it. It order to insure that the JBI achieves its goal as a work support system, we believe the user interfaces each member of the JBI staff must also be regarded as a support system that is organized in a manner that keeps the worker maximally "on-task" even as the characteristics of the work problem changes based on prevailing conditions. The agent-based direct manipulation interface attempts to achieve this goal by insuring the visible portion of the interface follows a stable and consistent, yet flexible, work-oriented ontology that can dynamically connect to any appropriate information source through an interface agent that mediates ontologically differences with delivery agents. The homogeneous work centric interface focus is maintained even as the user finds the need to drill down for more detail or drill in to inspect and evaluate vital aspects of information sources, which results in dynamic connections to a pool of heterogeneous server agents, data sources, and application tools.

It should be clear that on conceptual grounds our interface concept scales to the larger arena of full battlespace management. However, on a practical levels the design task may be more challenging. One issue revolves around the semantic mapping from an information/application tool domain to the work centric one of the user. The range of information types and tools will become larger and more diverse. Can effective semantic maps be found for all of them? Clearly it would be desirable if we could establish and validate semantic mapping principles that could be used to accomplish this task. A related issue deals with the extent of automation present in the software interface mediators. In order to achieve the desired semantic mapping, interface agents may have to take on more functions that will be opaque to the user. This increases the likelihood of miscommunication of the interface to the worker—the problem of automation surprise (Woods, Sarter, and Billings, 1997). Can this problem be avoided? More research may have to be directed in this area.

To date, we have completed a preliminary demonstration of our agent-based direct manipulation concept. Initial reaction has been very favorable, and a second demonstration is scheduled. However, to more thoroughly evaluate the concept, an experiment is needed that as a minimum measures the predicted on-task/off-task time advantage and correlates it with a mission performance metric. Further, additional research will be needed to address the implications for maintaining a work centric interface focus as the properties of the interface itself expand to include such things as multi-media, multi-modal, and adaptive characteristics. Can these properties be enfolded into the agent-based direct manipulation concept? What impact might they have on semantic mapping?

Our agent-based direct manipulation interface is the first attempt we are aware of to propose a concept for how to design a collected set of work centric interfaces to a heterogeneous information network. It goes beyond the issue of standard "look and feel" that dominates user interface design today. While it may not be the final answer, we believe it is at least a useful first step to enable the JBI vision from the perspective of each individual user

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Investigating the Information Presentation Design Space

Helen M. Gigley, Ph.D.
Office of Naval Research
Human System Science and Technology Department (CODE 34)
800 N. Quincy Street
Arlington, VA 22217-5660
USA
Email: gigley@itd.nrl.navy.mil

Summary: Military systems at all levels of decision making require the ability for the decision maker to find information, query it, seek refinement of it, process it in combination with other information, add value to it, make the decision and communicate the decision to another user. The US Office of Naval Research program in Interactive Multimedia and User-Centered Design supports research in how to employ technological capabilities to enhance a person's abilities to carry out the decision making objective. This paper will employ several research projects from this program to illustrate basic findings that impact how to design systems to meet this objective. Usability objectives require that design address the impact on the user's ability to perform the task. The research reported here, even though in domains or applications that differ from battle management are at the level of studies of enabling understanding of the design space. Reported results provide guidance and suggest how to design the information presentation in the appropriate form for its use.

First, basic assumptions behind development of the program will be described to set the context for the projects. Then, each project will be summarized presenting the research findings. The selected projects provide scientific bases for design decisions that impact how a person can actually use information in different presentation contexts, multimedia documents, multidimensional flat panel displays and in a Responsive Workbench context. Other research includes multiple modalities but will not be discussed here.

Background: The program in Interactive Multimedia and User-Centered Design assumes an integrated multidisciplinary approach to employing cognitive modeling and perceptual understanding in design of task-focused interactive systems. Teams of researchers include cognitive scientists, psychologists, computer scientists, and experts in experimental design in differing combinations. Research projects are theory and hypothesis based allowing effective evaluation to produce better understanding of the human component of a system and hence, contributing to effective system usability and design. Computational cognitive models such as ACT-R (Anderson, 1993) , COGNET (Zachery, Ryder and Hicinbothom, 1999) and EPIC/GLEAN (Meyer and Kieras, 1997a, 1997b) are being developed to provide resources for cognitive appraisal of design decisions.

In addition, building usable systems entails analysis of which modalities are best for what types of information or information use, such as vision, audition, or somatosensory, and what media can provide them, such as a monitor, film, 3-D sound, etc. The space is further complicated in that information presentation can have multiple modes that also differ in how a human can deal with them, such as in the visual modality on a monitor, one can have graphs and text, or text and an animated drawing or only text as modes. These three dimensions, modality, media and mode are being investigated for better understanding of their impact on the user's ability to deal with the information being presented.

With this brief introduction of some of the features of the design space that must be addressed to obtain effective design, the remainder of the paper will illustrate how some of them effect usability of information by presenting research investigating: Interactive multimedia document design; Visual presentation of information using perspective view technology, 2-D or 3-D on flat panels; and Usability in Virtual Environments (VE), user-focused information management in an immersive Responsive Workbench environment.

Paper presented at the RTO HFM Symposium on "Usability of Information in Battle Management Operations", held in Oslo, Norway, 10-13 April 2000, and published in RTO MP-57.

Interactive Multimedia Document Design: Dr. Mary Hegarty (University of California Santa Barbara) and Dr. N. Hari Narayanan (Auburn University) have teamed to investigate a cognitive theoretical model-based multimedia design for manuals that are intended to teach how devices work. Such manuals are a focus of many new requirements that insist on on-line information for training and reference. They are developing methods for presenting information to maximize the user's ability to understand causal relationships from it. Their theory includes a model of human states of comprehension of mechanical devices (the domain of previous work) and their operations. The theory includes a four step process in obtaining understanding of how a device works to be able to apply the understanding to a real world instance of the device. The theory of comprehension includes the following stages: Stage1: **Machine Decomposition** by diagram parsing; Stage 2: **Constructing a Mental Model**-- Making Representational Connections; Stage 3: **Constructing a Static Mental Model**-- Making Referential Connections; Stage 4: **Determining the Causal Chain of Events**; and Stage 5: **Constructing a Dynamic Mental Model** by Mental Simulation and Rule-based Inference (Narayanan and Hegarty, 1998).

Their method for design recognizes cognitive workload factors and attempts to reduce them during reading and studying of the material. They are studying how the integrated placement of text explanations and diagrams, both static and animated, contributes to the understanding of concepts and processes in a hyperlinked document. The model is based on previous work on relative location of text and graphics, showing that text associated with an image must be nearby and that labeling in the text must be clearly visible on the drawing (Hegarty, 1992; Mayer, 1989). They designed on-line documents, based on the theory of stages just described, in the context of understanding how a flushing cistern (toilet) works. Understanding requires inferring causal relationships after the components are recognized and integrating them with world knowledge about water flow and how the mechanical components work in isolation.

The initial design of the hypermedia manual integrating this theory produced a complex set of experiments to validate the theory. The studies compared learning and understanding using a hyperlinked version of the information as well as a static paper version, both were created using the theory of comprehension summarized above. The results indicate that presenting information in a hypermedia manual that includes hyperlinks, colored diagrams, animations (rather than static diagrams) and commentaries (rather than visual text) had no effects on comprehension. The same results were obtained by expository causal link information in the text and in some cases just a labeled diagram alone conveyed the same level of understanding. It seems that the juxtaposition of the structure and content of closely associated material is more important than the form of the document(Hegarty, Quilici, Narayanan, Holmquist and Moreno, 1999).

Among their findings is the fact that they were unable to adequately evaluate their theory and model of design and its predictions in the context of the document. Analysis of their results have suggested other ways to implement their principled theory in the context of interactive multimedia information presentations. Current work continues to find that the "message is more important than the medium" as far as using technology to enhance understanding or comprehension.

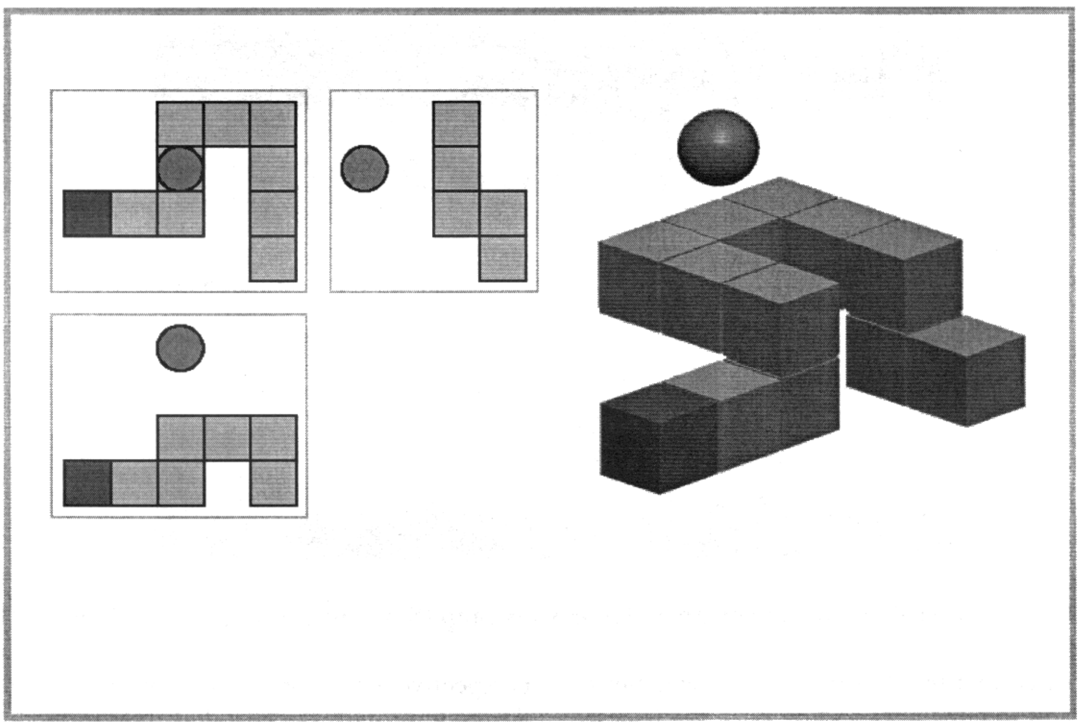
Additionally, Hegarty and Narayanan found, as has been documented elsewhere, that animation does not necessarily aid understanding and that it can confuse the user. Several results indicate that animation must be well integrated with text, or needs to be integrated into material in a manner that requires interaction with the concepts in addition to exploration of the animated rendering of it (Hegarty and Sims, 1994; Kehoe, Stasko, and Taylor, 1999).

They are continuing their investigation on understanding multimedia information using atmospheric weather as their focus. It is something, not directly observable but often visualized for understanding, such as weather front movements and wind speeds and directions. Users will be evaluated for their retention of information and understanding of causal relationships somewhat similar to the original study of how a pumping cistern works.

Others have been studying the effectiveness of animation in learning contexts. The fact that its role is controversial even though assumed to enhance learning has implications for the use of animation in battle management contexts. Dr. John Stasko and his Information Visualization Group (Georgia Institute of Technology) has shown that animation improves understanding in certain contexts and has been exploring how to best provide animation capabilities in learning systems (Stasko, 1996).

Empirical evidence suggests that application of animation in learning and possibly in understanding information in decision making environments may depend on knowledge of the context of application, the mental workload of the person, and whether the person has the ability to mentally visualize and dynamically manipulate it. In understanding algorithms, or software processes, when the person already understands a principle and is able to somehow visualize it, the animation seems to provide enhanced learning (Kehoe, Stasko, and Taylor, 1999). The animation provides additional depth of understanding. This was demonstrated in the context of animations to explain how software algorithms worked, a phenomena that has no real world visualization. It seems that animation is only useful as an enhancement to understanding when the person is already able to mentally visualize the action or concept.

Visual Presentation of Information Using Perspective View Technology: Drs. Michael Cowen (SPAWAR Systems Center-San Diego) and Mark St. John (Pacific Science and Engineering Group, Inc.) are investigating the role display formats play in the ability of a user to access and use information. The issue can be stated as, what type of information is best presented in what format? In a recent technical report (St. John and Cowen, 1999) results from experiments comparing two presentation formats to determine answers to the question about form and available content have shown that in tasks where relative position is important, the multiple projection 2-D presentation provides explicit information that can easily be determined with little error. In contrast, the 3-D presentation has increased ambiguity due to the perspective rendering of the same information. See Figure 1. If the task is to determine the shape or general configuration of an object, then the 3-D is superior to the 2-D multiple view perspective (St. John and Cowen, 1999).



Based on these results, subsequent investigations were carried out to determine the implications of these findings in an Area Air Defense Display. The system design included several 3-D presentations, of terrain and of icons, and the goal was to determine whether, the 3-D perspectives and realism enhanced situation awareness or merely provided a more satisfying feel to the picture. Examples of the icons used in the experiment are provided in Figure 2.

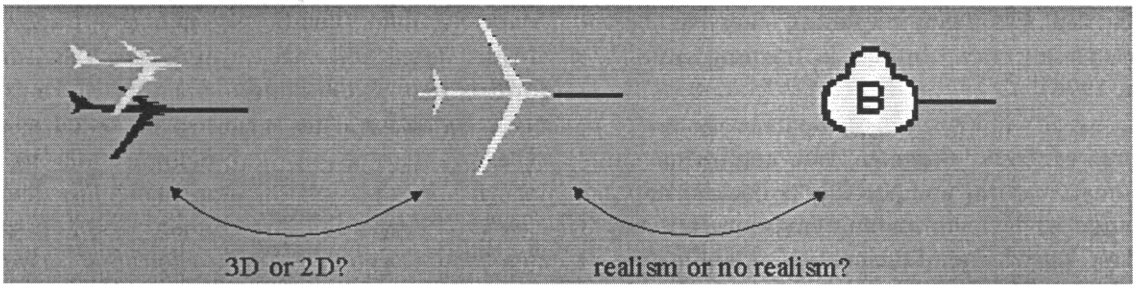


Figure 2: Examples of icon conditions for experiment, left to right, East heading bomber depicted realistically in 3-D, realistically in 2-D, and symbolically or non-realistically (Smallman, Schiller, and Mitchell, 1999).

The icons were overlaid on a flat panel 3-D terrain map in perspective view in one condition, and in planar view in the other two conditions. Tasks include track identification and monitoring to gain situation awareness. Relative ground position was provided by the corresponding shadow on the terrain surface in the perspective view condition. The scenario used was the same for all three conditions, 1) 3-D realistic icons on a 3-D perspective terrain presentation, 2) 3-D realistic icons on a planar terrain presentation (no shadows on surface and bird's eye view) and 3) 2-D non-realistic icons on a planar terrain presentation. Figure 3 shows the 2-D iconic representation on a planar terrain presentation as an example, condition 3 just discussed.

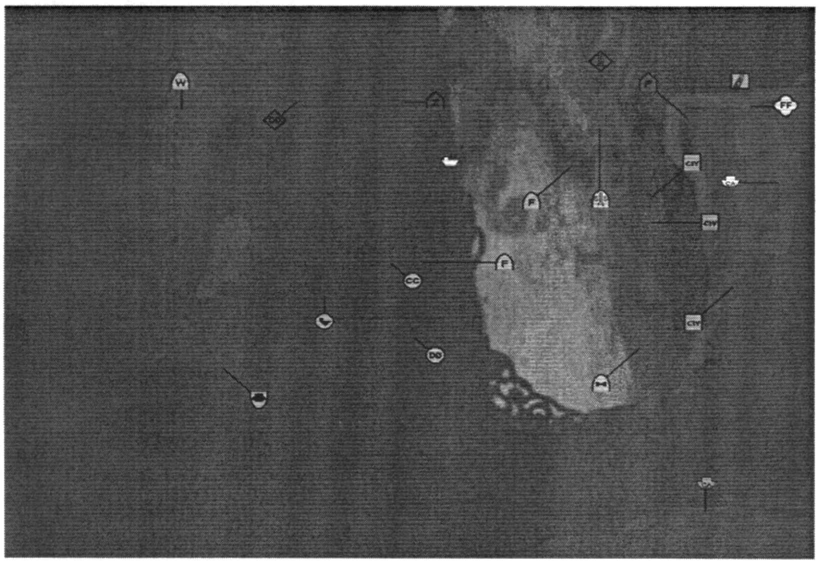


Figure 3: 2-D non-realistic icon view on a planar view map (Smallman, Schiller, and Mitchell, 1999).

Results showed that the 2-D iconic representations are the easiest to remember and produce the fewest errors on identification and reporting of the tested attributes. While the 3-D icon on the 3-D perspective terrain presentation was assumed by the design to provide the best depiction to facilitate the user task, the results showed that the opposite holds. Due to the foreshortening of the perspectives and the nature of the shadow connectivity with the icon, ambiguities are introduced that produce errors in the ability of the user to track the attributes of the object represented by the icon. In addition, when the icons are small due to the distance above the ground, it is very difficult to find the corresponding shadow for the aircraft. Decluttering the image may provide some help, but adds another subtask for the user. Furthermore, in the 3-D case, the light source and its effect on how the shadows appear introduces another aspect of ambiguity in the presentation. Details of these investigations and full results can be found in Smallman, Schiller, Mitchell, 1999.

Battle management systems require many tasks and manipulations of information similar to those that were used in these studies. The usability issues scientifically documented in these studies are important and generally ignored in current designs. Understanding limitations on visual presentation options and how they interact with user tasks and with user capabilities needs to be further explored.

Usability in Virtual Environments: On-going joint research by Dr. Deborah Hix at Virginia Polytechnic Institute and State University (Virginia Tech) and by Dr. Edward Swan II at the Naval Research Laboratory (NRL) focuses on methods for defining usability criteria in virtual environment (VE) design. Their recent award winning paper at the Virtual Reality 99 Conference, (Hix, Swan, Gabbard, McGee, Durbin and King, 1999) exemplifies a four step method of usability design that was verified while applying it in a Naval Battlespace context. This section will begin with an overview of a preliminary investigation into the state of usability for VE and will conclude with an overview of the methodology and its application in the battle management domain.

Initial questions regarding usability issues in VE arose during discussions about device selection and use and the fact that the metaphors for use in VEs are far more complex and allow many new interaction possibilities than any other technology to date. Additional evidence that human usability issues need attention has been documented in the findings that humans subjected to VEs suffer performance effects even up to an hour after they leave the immersion (Kennedy and Stanney, 1996). Previous enhancements to VE technology that focused on presentations, visual, auditory, haptic, and their refinement was able to only ameliorate part of the effect on the user. Since the VE provides an immersive interactive space for design and use, it presents a design challenge along a vast number of dimensions.

An initial effort to document a taxonomy of usability characteristics for VEs intended to begin a dialogue that would aid in understanding the design space at a theoretical level and that would aid in effective VE design. Dr. Hix with her then graduate student, Joseph Gabbard, began their effort to understand the usability issues regarding design of VEs. They did a thorough review of relevant literature, interviewed leading VE researchers and designers, and talked with practitioners and users of VE systems, chiefly in training or mission rehearsal domains. They found that the usability space for VEs included complex interdependencies, among users, user tasks, input devices, output devices, etc. The result of their investigation is a taxonomy of usability methods (Gabbard and Hix, 1997).

Employing known usability methods as a start point, they found that VE expanded their applicability to teams and integrated team tasks, as well as tasks that involved the whole human as opposed to using a system while sitting in front of a monitor. Immersion as part of usability requires new metaphors in thinking about what usability means. The framework in the document organizes user interaction design guidelines and discussion into four major areas: 1) users and user tasks, 2) input mechanisms, 3) virtual models, and 4) presentation mechanisms. All findings are cross-linked and documented with interview explanations or cross-referenced to other related usability. The document intended as a dynamic taxonomy, provides a broad definition of the state of usability in VEs. It is available as a public resource at URL: http://csgrad.cs.vt.edu/~jgabbard/ve/taxonomy. Figure 4 provides an overview of the taxonomy areas. This characterizes the complex design space and illustrates how usability can impact the design of VEs.

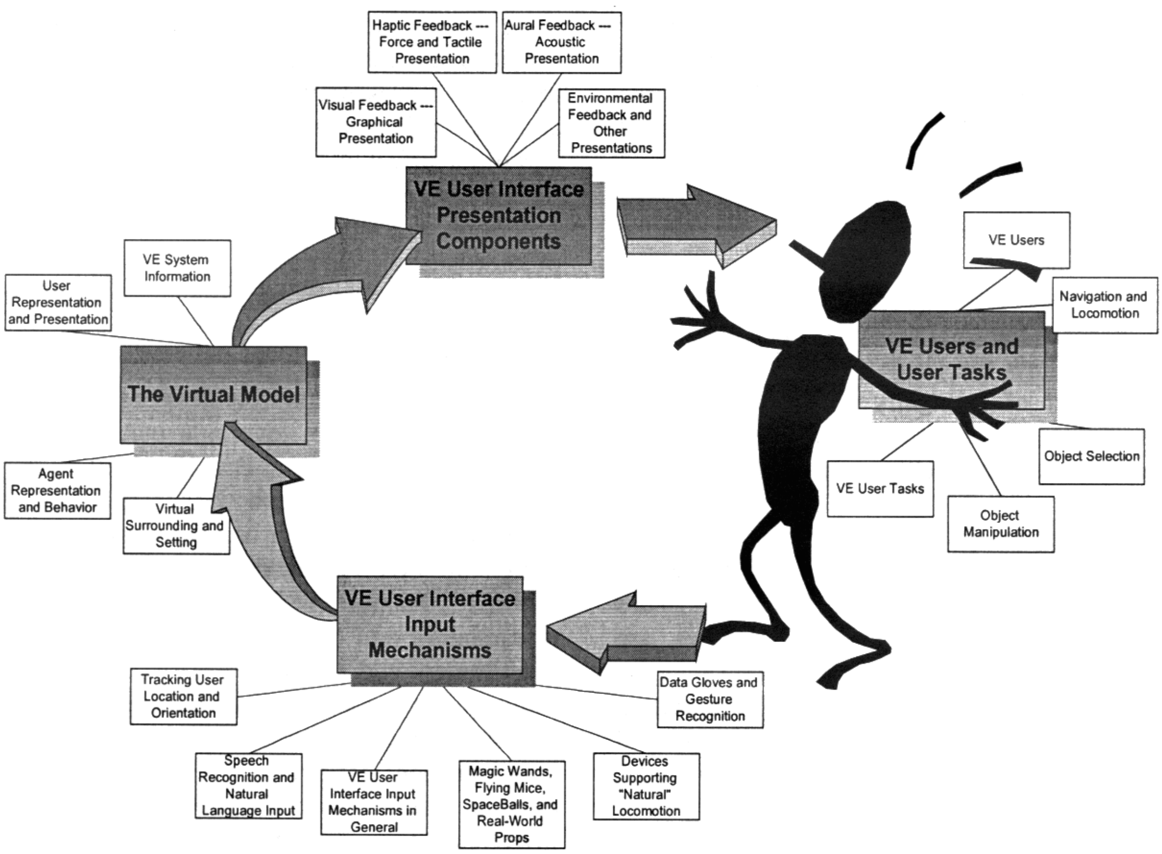


Figure 4: An Overview of the Taxonomy (Gabbard and Hix, 1997).

Follow-on joint work at NRL integrated many of the basic findings into a defined method for usability evaluation in the context of battle information management. This work employed an immersive environment on an Responsive Workbench. In addition to developing a suitable interaction device, the effort took approximately nine months to apply the usability method, validating it as the work progressed and in the end, producing a system that is ready for summative evaluation in the application domain.

This development has supported the fact that by carrying out the up-front usability design methods, life-cycle cost reduction can be realized. A few of the many discoveries in the context of this work will be summarized. Below, Figure 5, is the workbench environment, Dragon (Durbin et al., 1998), including the terrain and object renderings that form the basis of the design solution. It is the result of a successful application of the design, test, design cycle of usability assessment. Details of the effort can be found in the Virtual Reality 99 paper referenced above. The methodology is elaborated in Gabbard, Hix and Swan, 1999. The usability method includes a four step assessment, based on the design space presented in Figure 4. The user-centered methodology assumes sequential performance of the following 4 steps: 1) user task analysis, 2) expert guidelines-based evaluation, 3) formative user-centered evaluation, and 4) summative evaluation.

Cyclic evaluations are performed as design problems arise. As more problems are eliminated in the early phases, the cost of implementation and subsequent possible modification are reduced. The four steps will be briefly described In the context of developing the interface design for navigating within the Dragon workbench environment.

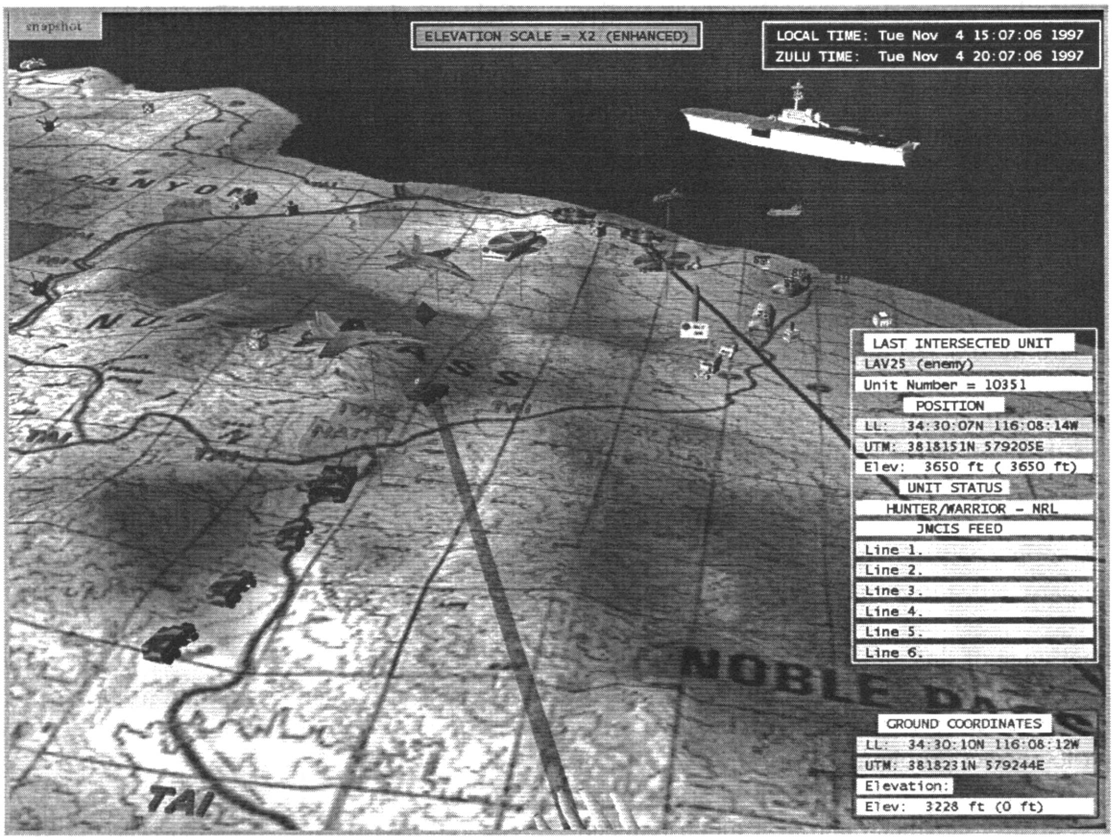


Figure 5: Dragon Responsive Workbench Design (Hix et al., 1999)

1.
1. **User task analysis:** must include an understanding that is as comprehensive as possible of the tasks the user will be doing and the goals of the total system use to achieve good user-centered design. It was found very early in working with the workbench, that the ability of the user to move around, locomote, to find the information they need is critical to any other tasks. Therefore, the task selected to implement and evaluate the method became locomotion.
2. **Expert guidelines-based evaluation:** identifies potential usability problems by evaluating a user interaction design against what is known by experts to be sound design principles. Any violations are revisited and the design is redone to address them. Multiple experts perform the evaluation, independently and then in joint discussion. During this phase in the design of Dragon, experts discovered a major problem of poor mapping of locomotion tasks (pan, zoom, pitch, heading) to flight stick buttons as well as problems with inadequate graphical and textual feedback to the user about the locomotion.
3. **Formative user-centered evaluation:** requires careful definition of scenarios that will exercise the interface under the set of tasks included in the design. In the Dragon design of locomotion, the initial control was to allow the user to move the map relative to themselves. During formative evaluation, users indicated they wanted to be able to fly over the terrain. This input suggested a different design that was developed to allow movement in exocentric (the map movement) and egocentric ways(the fly –over). Subsequent evaluations were carried out to build the right responsiveness into the interface to adequately capture the control from the user's perspective for both these metaphors. This evaluation includes data collection about user's performance that guides the design for the system.

4. **Summative evaluation:** requires comparative evaluation between several competing designs. This is a formal evaluation of the implemented user-focused interface. The affects of exocentric vs egocentric control are one variation being studied in Dragon. To effectively test this, all actions must be accomplishable in both systems to be able to compare measures that will determine the best design. Speed of problem solving is one such measure as is correctness of solution. For this type of evaluation an adequate scenario test set must be defined that drives the interface use in ways that will stress its functionality to firmly determine the best solution. Summative evaluation focusing on egocentric versus exocentric control is currently underway (Gabbard, Hix and Swan, 1999.)

The importance of this applied methodology is that the right level of detailed evaluation is performed at the right time during the design, saving extensive redesign to correct problems late in the cycle. The possibility of achieving an adequate and effective system is greatly enhanced and at a much reduced overall cost.

Conclusions: Usability methods have many applications in military systems. We are just beginning to understand some of the underlying cognitive aspects that are reflected in how people can obtain and use information. As more interdisciplinary conversations occur between cognitive scientists, usability engineers, human-computer interface designers and domain experts we will see a positive change in the design of systems—more usable by more people without restrictive selection criteria and the overall result will be a cost reduction in the life-cycle costs of the systems.

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URL for Chi Systems Inc.: http://www.chiinc.com.

COMPONENTWARE APPROACHES IN MANAGEMENT INFORMATON SYSTEMS

Dipl.-Ing. Jürgen Kaster, Dipl.-Ing. Annette Kaster
Ergonomics and Information Systems Department (EFS)
Research Institute for Communication, Information Processing, and Ergonomics (FKIE)
Research Establishment for Applied Natural Sciences (FGAN)
Neuenahrer Str. 20, D-53343 Wachtberg-Werthhoven, Germany
Tel: [+49] (228) 9435 - 380, Fax: - 508
j.kaster@fgan.de, a.kaster@fgan.de

Summary

Modern command and control information systems (CCIS) are characterized by continuously changing conditions regarding technology, task and user profiles. As a consequence of this heterogeneity a huge amount of information and knowledge pieces of different data types has to be managed and processed in distributed communication networks. The situation in military CCIS is even more complex, regarding e.g. new requirements and multi-national command structures in actual out-of-area missions.

The paper will focus on architecture models on the basis of "*componentware technology*". Pursuing the proposed ideas may help to design systems of high flexibility that can be adapted to actual user needs and task requirements.

1 Challenges in the design of CCIS

Military CCIS are developed to solve operational requirements in the areas of situation identification and assessment, planning, decision making, and commanding. Appropriate timely information flow has to be provided over large, distributed communication networks. However, problems in actual command processes are not mainly induced by the complexity of military structures. There are three major influence coefficients that induce that those systems are unstable over time. These influence coefficients are rapidly changing conditions regarding applied technology, operational requirements, and heterogeneous user profiles.

In most cases it is not possible to design military information systems from scratch that have an overall consistent hardware and software basis for the technical and conceptual implementation. Operational requirements cause continuous updates and adaptations. As a consequence a rather *heterogeneous environment* evolves in which command and control processes must be embedded. Of course, this complicates the realization of an universal support concept and induces interruptions of the required communication flow. Information may be falsified or even lost.

Another problem derives from the fact that operational *mission requirements* have dramatically changed in the last few years. Out-of-area missions have to be planned, prepared and executed within a short time. Task forces have to be established in accordance to actual needs. This requires extremely high flexibility and adaptability of the underlying technical support systems. Additionally, multi-national missions and command structures are nowadays a matter of course.

A third problem area is the need of supporting total different *user profiles*. Users show discrepancies in their technical and professional competence, working styles, and they have different tasks to fulfill at the same system or system components.

The consequence is that the realization of universal and stable concepts in military CCIS is very difficult or even impossible. The well known problems, which are paraphrased by "software crisis", are established mainly by impediments in a *timely and task-oriented access* to information and knowledge that is stored somewhere in the system.

The challenge for improvements of CCIS from a human factors point of view is to provide direct problem-oriented access to the information that is actually needed in current operational situations. The next task is to make the human-machine interface as homogeneous as possible even in modern multimedia environments. The reason is that learning processes can be simplified if there is a high value of recognition implicitly in the applied dialogue procedures. However, one has to take into account that information items may change their characteristics during processing and evaluation. For example, a broad range of textual input details may be aggregated and transformed to other presentation categories to support decision processes at a higher command level.

To overcome restrictions and insufficiencies in military CCIS, it is necessary to make more efficient design concepts and processes available. Componentware technology is a new paradigm, that allows to construct flexible system architectures (macro-view) as well as concrete military application software (micro-view). The following chapter will focus on this technology.

Paper presented at the RTO HFM Symposium on "Usability of Information in Battle Management Operations", held in Oslo, Norway, 10-13 April 2000, and published in RTO MP-57.

2 Componentware – a new approach for CCIS development

2.1 Componentware as an extension of object-oriented techniques

The transfer from former procedural views to object-oriented software techniques introduced totally new ways of thinking and abstractions to the software engineering process. Object-oriented analysis (OOA) and object-oriented programming (OOP) emphasize concepts like e.g., abstraction, modularization, and reusability. However, object-orientation is limited to the reflection on technical structures like program and system objects and their interrelationships.

"As a system becomes more complex, the design problem goes beyond the algorithms and data structures of the computation: designing and specifying the overall system structures emerges as a new kind of problem" [Booch et. al. 1999]. In order to address this citation it is necessary to provide methods which represent a system as a whole assembled by independent but interacting components. *Frameworks* are general system models which structure the application in cooperating building blocks. Recently the *componentware* principle offers solutions to develop applications which are based on such frameworks (Schreiber-Ehle 1999). This technique defines standardized protocols which independently developed programs can use to communicate (Microsoft 1998; OMG 1998). If this technique is applied modules can be exchanged (even at runtime). Therefore, modifications of the system and its performance can be achieved even after the software installation process has been completed (Plasil et. al. 1998).

A software component is an executable piece of software that provides a useful, in the application context valuable functionality. It offers plug & play readiness for service and is cooperative in combination with other programs (Griffel 1998). The *component view* has its value in the emphasis of delimitations and independencies of software elements in supplementation to internal views on program and system objects. Components are independent application-oriented building blocks with well defined interfaces to other application software. Despite the required originality of a software component it becomes a "real" functional component (as a part of the whole) only in combination with others. This will result in a growing significance of modern framework techniques (as a model of the whole).

The component view may be applied to an entire information system as well as to special application software. This dualism is also important considering the design pattern which is introduced in the next chapter.

2.2 Model-View-Controller: Design pattern for improved data management

In order to create a suitable software architecture consisting of independent exchangeable parts the use of *design patterns* is helpful (Gamma et. al. 1995). Design patterns structure logical dependencies on a high abstraction level. They are applicable to a software design in general and they supply designers with ready-made design solutions. A useful architectural pattern to create componentware systems is the Model-View-Controller (MVC) paradigm.

An optimization of user interfaces as well as assistance systems according to ergonomic criteria is indispensable for an efficient support of complex command and control tasks with computer-based information systems. There have been benefits provided by the construction of separate user interface management systems (UIMS) in complex applications (Myers 1995). However, most of the applied software products are rigid monolithic blocks that cannot be adapted to current needs. The reason is that the internal data management is strongly tied to algorithms and computations.

The goal of the Model-View-Controller (MVC) design pattern is - in addition to the mentioned separation of the UIMS ("controller") – to separate the application object ("model") from the way it is represented to the user ("view"). This leads to a system structure as illustrated in fig. 1.

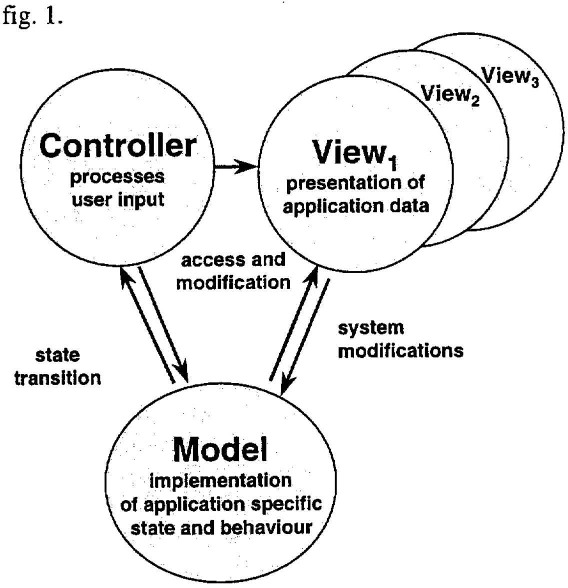

Figure 1: Model-View-Controller Design Pattern

Chapter 3.1 gives an example of a program that follows the MVC design concept. In a more general view, the MVC concept means, that in modern workstations which are normally used as front-end in CCIS, the data storage should be separated from the applied programs and tools. This can be done when powerful database management systems are available in a client server environment. When data storage and data processing capabilities are separated, user- and task-oriented systems can be developed that control the information flow between database and front-end tool.

This resulting flexibility in the construction of appropriate user interfaces will be demonstrated by a case study which is the topic of the next chapter.

3 Design of Human-Machine Interfaces based on Componentware Technology

The following case study demonstrates the benefits of the use of componentware technology which was introduced in chapter 2.

3.1 Scenario

In a former military conflict it was necessary to maintain a list of mine accidents which happened during the crisis. The task was to provide the appropriate information in an event list which was part of a situation report. This report was generated as a series of PowerPoint slides. Therefore it was decided to maintain the event list directly as a table in the presentation program.

Obviously, this way of "data managing" violated the MVC design pattern and comprised a lot of disadvantages. Problems occurred in the handling of the data (almost manual processing and formatting) and last but not least the data were not available for further use in the command and control process.

The current situation illustrated by this scenario emphasizes the necessity to conduct research on the scientific conception of improved task and user adaptable support systems based on systematic task and system analyses. Two examples will be presented below.

3.2 Application example (1)

The componentware approach is not only applicable to improve the architecture of a total CCIS (macro-view). It can also be used to construct concrete military application software (micro-view). The following is an example of such an improved military-off-the-shelf product (MOTS).

To study the impact of componentware architecture a military situation display system has been modified and implemented as a component. The complete human computer interface is now made up of commercial-off-the-shelf products (COTS), like word processor, presentation tool, image editor, and specialized elements, like situation editor (Kaster 1998) as well as geographic vector and raster map display and creation programs.

All these components can be put together at runtime according to the actual operational requirements. To achieve a smooth exchangeability of the specialized component elements the underlying software design is structured by strict separation of the user interface from the remaining system functionality. This separation means, e.g., that dialogs are implemented as independent components as well as menu bars. They do not belong to the kernel of the system. Therefore they can be easily replaced, even by third party components (e.g., a new color selection technique).

Furthermore well known design patterns (Gamma et. al. 1995) such as *Model-View-Controller* (MVC) paradigm, *Presentation-Abstraction-Controller* (PVC), and the *Factory* pattern have been used to group the parts logically. Because of the underlying structure of the MVC concept the user can choose between different means for presenting information, like graphics with or without geographic background, textual output of object structures and attributes (fig. 2), and for manipulating input data.

3.3 Application example (2)

Within the existing client/server infrastructure an alternative concept has been developed on the basis of a professional database management system. According to the requirements of the afore mentioned MVC pattern results from the analysis of the application domain were transformed into a database design (model) and an application design (view). While the underlying development process is described in chapter 4 the resulting application components and user interfaces are illustrated below.

Fig. 3 shows a standard input mask for mine incidents with sophisticated assistance for filling in the form, i.e., entering values for parameters and attributes describing an incident.. Fig. 4 contains several different views on the same data which are designed for the executive level of users. Furthermore, in the componentware environment it is possible to exchange data with other presentation tools (e.g., preformatted Excel spreadsheets, PowerPoint slideshows).

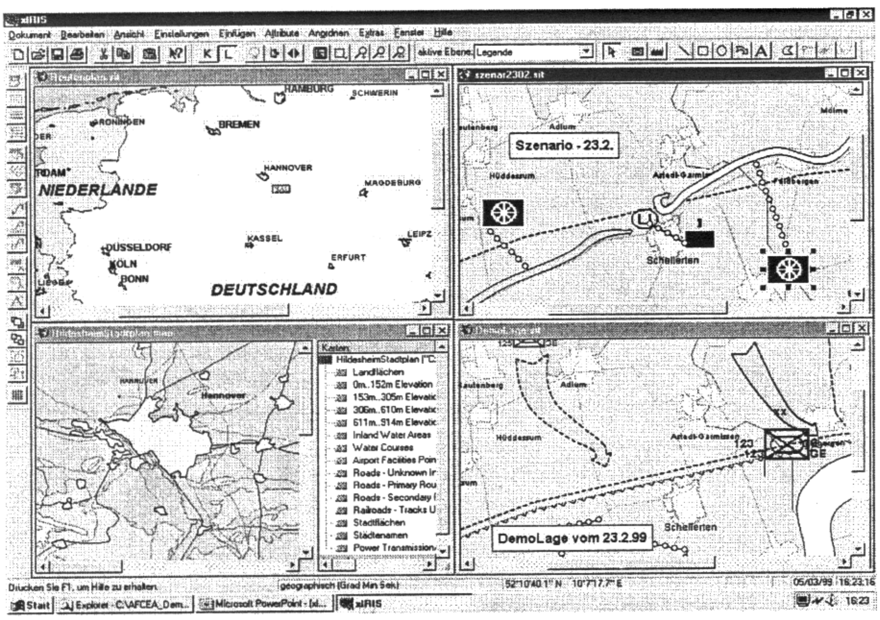

Figure 2: Situation data presented in a multiple windows environment.

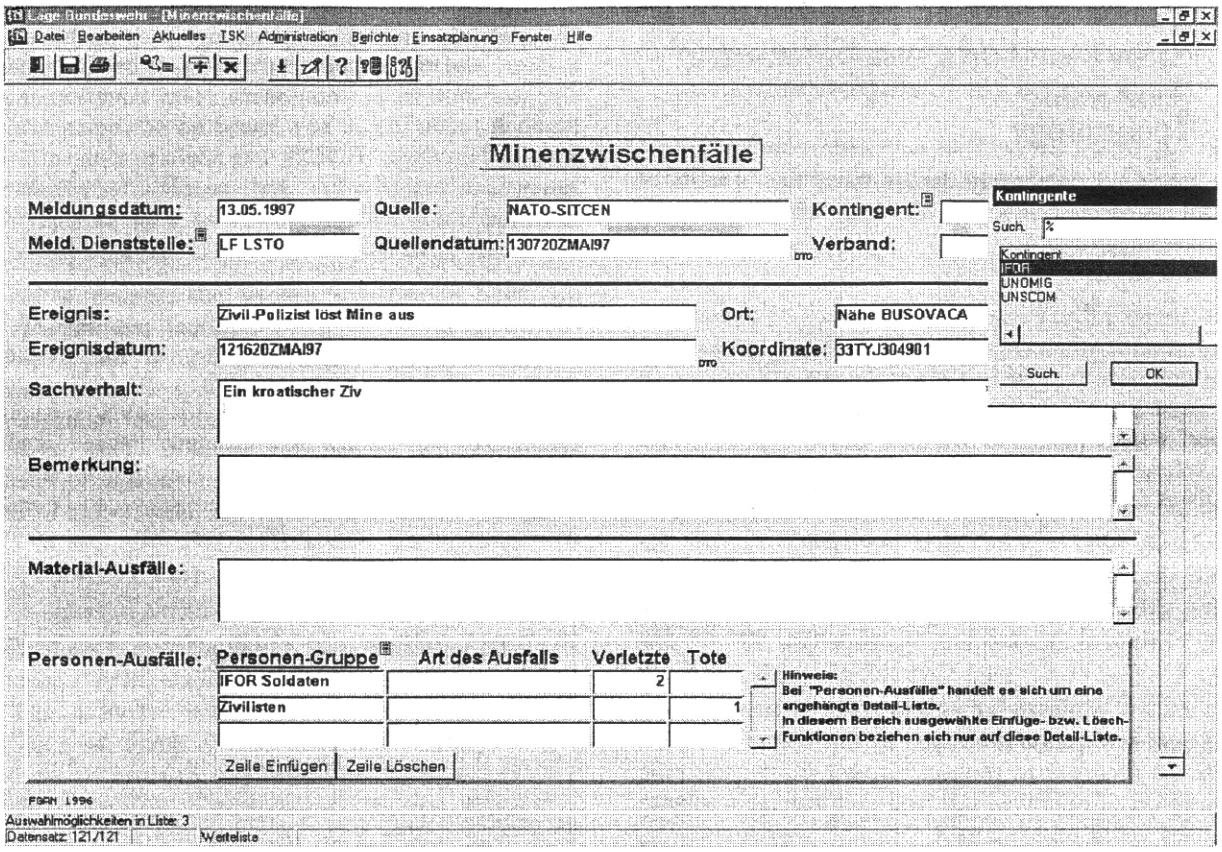

Figure 3: Scenario “Mine incidents” - input mask

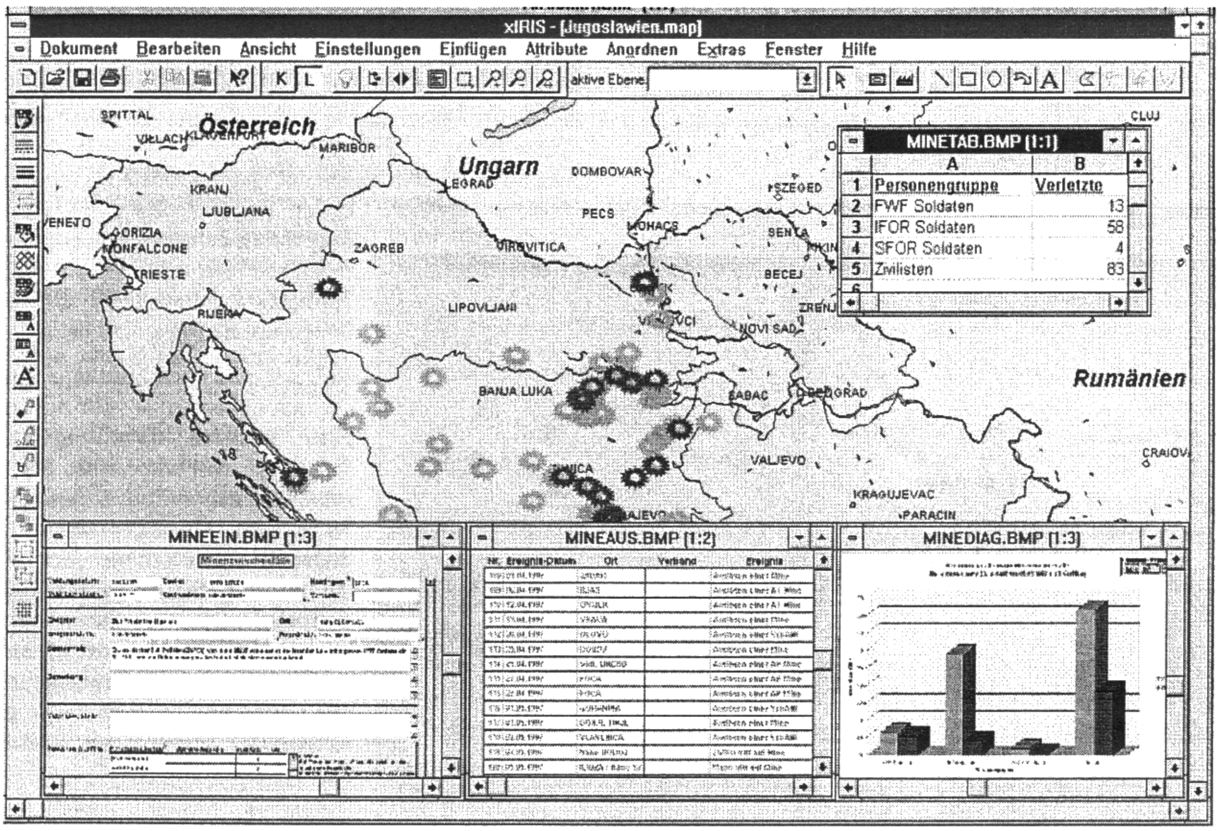

Figure 4: Scenario “Mine incidents” – different views

4 Rapid Application Development of CCIS based on CASE Technology

The advantage of components is their universality. However, it has to be taken into account that this flexibility may cause problems in the management of the total system. This is especially true in military CCIS of high complexity. Such systems comprehend a high quantity of data and often show a wide variety of heterogeneous data. In addition, there are various prerequisites according to the different user groups for the interaction with the data. There are requirements for inputting and manipulating as well as for analyzing, evaluating and presenting the data. There is, after all, the necessity for making important decisions in short time based on presented information. The aforementioned characteristics require especially that human factors principles have to be incorporated in the development of the user interface.

As mentioned before, a well defined framework needs to be defined, so that independent components can be embedded and cooperate as generic parts of a system. Within this framework, is may be necessary to modify components in a short time. Rapid Application Development (RAD) techniques allow an evolutionary implementation and optimization of components. This will be demonstrated for typical database applications.

The approach described herein deals with the application of integrated CASE technology (iCASE)[1] (Hoppe and Mempel 1998, Kurbel et al. 1994) in the development of ergonomically designed user interface components for a database of a CCIS (Kaster et.al. 1999). The technical platform is the Oracle Developer Suite.

4.1 CASE Technology - Bridging the Gap between User Requirements and Information Systems

The architecture of modern information systems is characterized by a decentral processing along with central administration of information. In order to use the data interactively within this client/server architecture consistent and transparent interfaces have to be developed. These enable task and situation dependent access, input and recherché of database information.

Figure 5 illustrates a general procedure to design a system using CASE technology. Based on the analysis of user requirements the application of CASE enables an almost fully automated and standardized creation of user forms for accessing the database. The application domain is structured in organizational items and processes (business process model). In the following system modeling phase information objects of the process model are represented in an entity relationship diagram (ERD) and functions are defined in a function hierarchy diagram (FHD). In using so-called wizards the application software is nearly automatically developed. The entities are transformed into tables of the database (database design) and the functions are transformed into the application design.

At this point available techniques of CASE were utilized to incorporate *ergonomic principles* in the design process of the application user interfaces. Oracle CASE offers the use of *libraries*, where the functionality of different forms is defined and stored in form of centralized, reusable and consistent code. It allows the definition of *preferences*, where general adjustments about layout, e.g. scrollbar position, take place. Furthermore, *templates* are used, e.g. to define the exact information about the layout of the header or footer or the button palette. Last but not least, reusable *master forms* can be defined, in order to avoid redundancy and to assure consistent behavior of several application forms in an object-oriented manner.

Using the description of the application domain in the repository and the predefined dialog components as well as presentation rules a consistent layout of the user interfaces is created. Integrated support functions enable user guidance and user assistance in operating the application forms, e.g. semi-automated filling of the masks, locking fields depending on user input, offering list of values for valid input as well as online help. The rapid application development supported by CASE allows an evolutionary development process and gives the chance for early user feedback.

4.2 Application of CASE

The heterogeneous data-sets in military command and control systems ask for various views on the data in order to satisfy user needs as well as to fulfill task requirements. Consequently, the visualization of the data has been conducted in various manners (Fig. 3 and 4).

(1) Using the CASE technology the data were visualized by several Oracle database tools. FORMS enables interaction in tabular form, GRAPHICS supports pictorial representation, and REPORTS generates written protocols.

(2) According to user requests the forms were connected with Microsoft Office tools. Forms with free text were coupled with WORD, tabular data were coupled with EXCEL, single documents can be transformed to PowerPoint in order to prepare presentations. In this manner users can work on their data in familiar environments.

(3) Another connection took place with a situation display program. Here, the forms are displayed as dialog components on digital maps, where interaction results in the modification of the situation represented on the map.

(4) In order to fulfill the requirements for an universal user interface the presentation of the database information can be presented based on Internet technology. The user can access the database via a commercial web browser.

[1] iCASE = integrated Computer Aided Systems Engineering

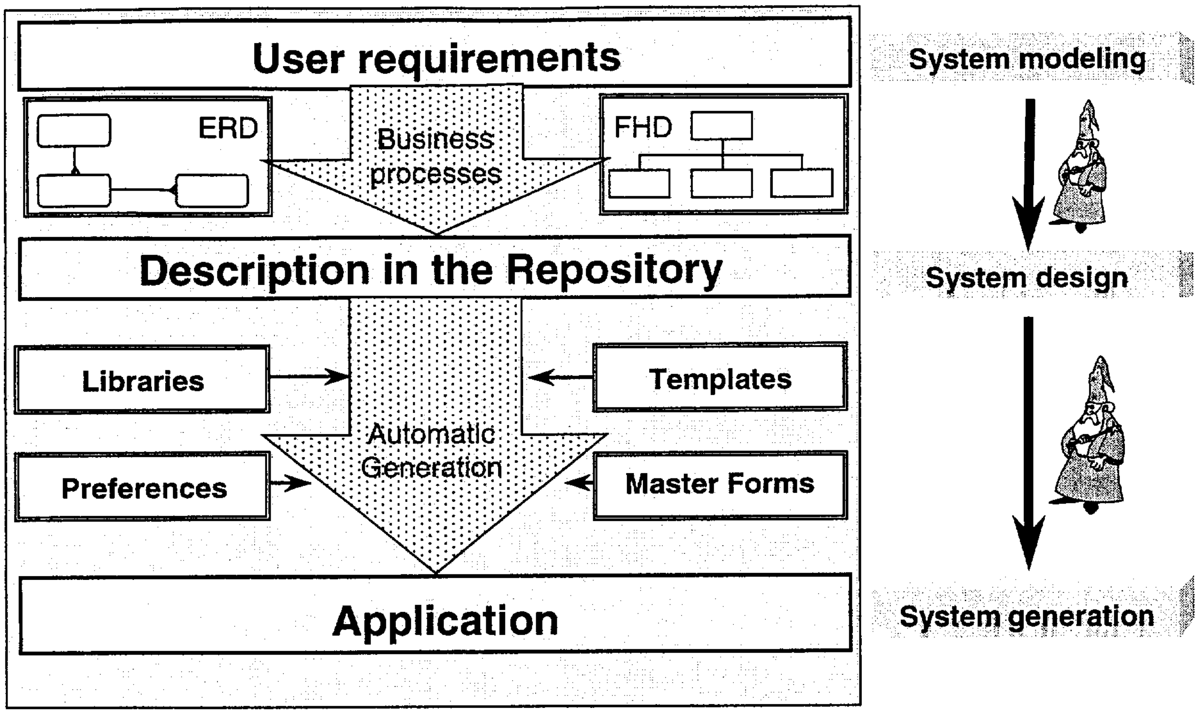

Figure 5: System design with iCASE technology enables the implicit incorporation of ergonomic principles

5 Conclusions

Current problems in the use of CCIS are often caused by insufficiencies of the human-machine interface. In order to overcome these problems it is necessary to take notice of strategies which help to create task oriented user interfaces that fulfill the requirements specified in ergonomic standards (ISO 1995, VDI 1990).

Componentware approaches provide means that support the practical realization of systems based on precise theoretical concepts. Design patterns help to structure the application domain by delivering ready-made design solutions.

Besides theoretical aspects, toolkits are required that support complex development processes. In this paper Rapid Application Development was referred to as a way that provides solutions in a short time. This method allows early user participation which is extremely important from a human factors point of view. The user interface for the access to the heterogeneous data can be created by using iCASE technology. Such a platform can provide the basic means to explicitly incorporate ergonomic knowledge in the design process.

The paper presented examples for benefits of componentware technology in a macro-view (considering a system as a whole) as well as in a micro-view (designing specific MOTS products).

In the research project it was demonstrated that the application of componentware allows the creation of interfaces in individual user environments in a consistent, complete and standard conform manner. The use of Internet technology will strengthen this effect.

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Quelle Assistance pour la Gestion des Missions Tactiques ?
A Propos du Projet Copilote Electronique

Dr. J.Y. GRAU, Dr. S. HOURLIER et Pr. R. AMALBERTI
Institut de Médecine Aérospatiale du Service de Santé des Armées
BP73, 91223 Brétigny-sur-Orge Cedex
France

Summary. Aircraft automation has forced designers to enhance their systems with aids to keep the pilot "in the loop". The development of assistance systems are in line with the evolution of "human factor" knowledge. Drawing from the concept of human-centered design, we introduce new assistance systems based upon Man-Machine-Environment interactions. Applied to fighter aircraft, these concepts gave birth to the "Electronic Copilot" program. The Electronic Copilot is a cooperative aid. It is aimed at helping the pilot operate at his best cognitive compromise. The philosophy and the Electronic Copilot program itself are described in the paper. The last part is dedicated to the lessons to be drawn from the program. Beyond any technical issues and the challenge of designing with Knowledge based systems and Artificial Intelligence technology, the assistance principles evaluated in this study appear to be promising if humans are ever to stay in the loop of complex system control.

1. INTRODUCTION

Les aéronefs de dernière génération offrent grâce à leurs capacités manœuvrières et à leurs systèmes embarqués plus de possibilités d'emploi que leurs prédécesseurs. L'équipage dispose continuellement d'un flux d'information qu'il doit sélectionner et analyser. Les missions s'effectuent dans des cadres tactiques où l'aéronef n'est jamais seul. Les décisions doivent tenir compte d'un dispositif global qui prend en compte les composantes aériennes, terrestres voire navales qu'elles soient amies et ennemies. Les contraintes temporelles sont fortes et pèsent à tout moment sur les mécanismes de perception, de compréhension et de prise de décision. Face à cette complexité, aider l'équipage est le souci permanent des concepteurs. Si l'on compare le cockpit d'un avion de combat actuel à celui d'un avion des années 70, les évolutions sont évidentes : les sources d'informations se sont multipliées, les informations sont de plus en plus symboliques, les moyens de communication homme-machine utilisent de plus en plus de modalités et des tâches entières sont déléguées à des automatismes.

Malgré ces évolutions, l'équipage est toujours considéré comme le facteur limitant de la performance homme-machine. Devant ce constat, la notion d'aide et d'assistance à l'équipage est essentielle dans le processus de conception des futurs aéronefs. Quelle aide doit-on apporter à l'équipage pour qu'il reste maître de la situation ? Les principes d'élaboration des aides reposent sur différents modèles des relations homme-machine. Force est de constater que pour dépasser les limites des aides actuelles et envisager les futurs systèmes homme-machine, il faut mieux prendre en compte la dynamique de la cognition humaine en situation de travail. A travers cet article, on se propose de présenter les principes d'élaboration d'une aide "intelligente" au pilotage pour avion d'armes avant de présenter les enseignements d'une étude portant sur la conception d'une assistance au pilotage, le programme "Copilote électronique". Réalisé dans le cadre d'un développement exploratoire soutenu par la Délégation Générale de l'Armement du Ministère de la Défense, ce programme a rassemblé 5 industriels de l'aéronautique (Dassault-Aviation, Dassault Electronique, Matra, Sagem et Sextant-Avionique) et l'Institut de Médecine Aérospatiale du Service de Santé des Armées (IMASSA). Seuls les aspects propres aux facteurs humains et sous la responsabilité de l'IMASSA seront traités dans cet article.

2. QUELLES AIDES POUR L'OPERATEUR ?

2.1. D'une approche techno-centrée aux approches centrées sur l'utilisateur

Pour aider le pilote à répondre aux contraintes des aéronefs de dernière génération, il est intéressant d'analyser l'évolution des principes de conception des aides existantes. L'approche techno-centrée de la conception des cockpits qui prédomine depuis les années 70 s'est rapidement contentée d'une vision restrictive de l'homme au travail pour ne souligner que ses limitations. En conséquence, il faut remplacer l'homme dès qu'on le peut par des

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systèmes automatisés qui sont plus fiables. Mais la difficulté vient du fait qu'on ne sait pas totalement suppléer l'être humain, en particulier pour les tâches intellectuelles de haut niveau où adaptation et créativité sont les garants de la sécurité et de la performance. Il en résulte que les aides apportées sont plus guidées par le savoir-faire technologique que par les besoins de l'opérateur. Sur un plan pratique, on automatise ce que l'on sait faire et à charge pour l'opérateur d'assurer la cohérence de l'ensemble (principe du "left-over"). C'est ainsi que sont rapidement apparus certains paradoxes de l'automatisation :

- Perte de compétence due au manque de pratique pour les tâches réalisées par les aides (1) ;
- Mauvaise représentation du fonctionnement des aides et donc difficulté à comprendre la situation (2) ;
- Apparition de nouvelles erreurs dues aux aides (3) ;
- Nécessité encore plus grande de l'opérateur lorsque le système d'aide est défaillant (4) ;
- En réduisant la charge de travail, l'aide induit pour l'opérateur un état de sous-charge qui est responsable d'une perte d'efficacité lorsque survient une situation critique (5).

Il ressort de ces paradoxes le besoin d'une meilleure compréhension des règles de couplage entre l'homme et la machine pour définir une conception véritablement centrée sur l'opérateur. On ne peut plus se contenter d'un partage des tâches en fonction des points forts de l'homme ou des automatismes comme le préconisait Fitts (6). L'allocation de fonctions entre l'homme et la machine doit être basée sur un principe de complémentarité et non de compétition (7). Plutôt que de se baser sur les limitations des composants du système, le principe est de voir comment les hommes et les machines peuvent se compléter et s'aider mutuellement. Les fonctions des hommes et des machines sont mutuellement dépendantes et nécessaires pour réaliser le but (8). De plus, cette allocation doit être dynamique pour permettre la flexibilité du système socio-technique (9). Une allocation trop statique va rendre difficile, voire impossible la flexibilité humaine qui permet à l'opérateur de s'adapter aux contraintes des situations en fonction de ses propres ressources.

2.2. Les approches centrées sur l'homme

Depuis l'émergence des facteurs humains, la conception centrée sur l'opérateur a pris plusieurs formes. Derrière ces différentes approches se cachent des modèles du fonctionnement humain. Le modèle le plus ancien est de considérer l'être humain comme un système de traitement de l'information dont les capacités dépendent des capacités et limites des sous-systèmes qui le composent. L'aide que l'on apporte à l'opérateur vise alors à optimiser les capacités de chacun des sous-systèmes (par exemple, le système visuel ou les capacités de mémorisation). Fortes de ce courant, de nombreuses améliorations ont pu être apportées dans la conception des interfaces pour aider les opérateurs à mieux interagir avec la situation de travail. Cependant une limite de cette approche est rapidement apparue avec la nécessité pour les opérateurs d'utiliser simultanément plusieurs de leurs sous-systèmes, par exemple lire une information sur un écran et retenir l'information perçue. Dans ce cas, connaître les caractéristiques de la perception visuelle et de la mémoire humaine ne suffit plus à décrire et expliquer le comportement humain en situation dynamique.

Un autre modèle complémentaire du précédent peut alors être utilisé, celui des ressources attentionnelles (10). L'attention est l'application volontaire de l'esprit à un objet précis, elle est une instance de contrôle et d'orientation de l'activité (11). Les ressources attentionnelles sont limitées et ne permettent pas de tout faire simultanément et de façon exhaustive. L'opérateur doit orienter son activité en fonction des caractéristiques de la situation et de ses intentions. Le principe des aides est alors de permettre à l'opérateur de faire ou de contrôler le plus de choses possibles sans que ses activités ne dépassent ses propres capacités attentionnelles. Deux voies sont possibles pour aider l'opérateur :

- Instaurer une étape intégrative entre les éléments bruts de la situation et l'information présentée à l'opérateur. L'aide consiste à donner aux informations un contenu symbolique plus important pour faciliter les hauts niveaux de traitement. L'aide peut aussi consister à faciliter la disponibilité de l'information en fonction de la situation et des contraintes de l'opérateur. Dans ce cas, la difficulté réside dans l'élaboration d'un modèle prédictif de l'activité. L'absence de prise en compte de la variabilité interindividuelle, de la gestion des événements non prévus et de l'activité réelle des opérateurs n'a pas permis de proposer des aides concluantes à partir de modèles normatifs de la tâche (12). Cependant ce principe d'aide est toujours d'actualité à travers la notion d'aide adaptative ("adaptive aids" pour les anglo-saxons) mais il faut alors le recentrer sur l'analyse de l'interaction entre l'opérateur et l'environnement.
- Décharger l'opérateur d'une partie de son activité. Cette voie est celle de l'allocation des fonctions entre l'opérateur et l'aide. Le principe d'allocation complémentaire est maintenant admis et de nombreux travaux vont dans ce sens (13,14). On parle d'allocation "complémentaire" dans la mesure où l'opérateur humain et l'aide constituent un système cognitif distribué dans lequel les mécanismes de traitement de l'information de

l'opérateur sont en équilibre dynamique avec l'aide. L'allocation est alors dynamique et dépend fortement de l'interaction entre l'opérateur et la situation. L'ensemble des travaux sur le partage des tâches montre que la délégation d'une tâche à une aide ne peut jamais être totale pour l'opérateur. L'opérateur est toujours le décideur final et au minimum il doit s'assurer du bon fonctionnement de l'aide (15). Face à une aide, l'être humain n'est pas un opérateur passif mais bien le superviseur d'un système automatisé subordonné. Son attitude et son comportement dépendent de la représentation qu'il a des compétences de l'aide et de la confiance qu'il peut lui accorder.

Une autre vision de l'homme au travail pour concevoir des aides est celle décrite par les approches de la cognition "située". L'activité humaine vise en permanence à assurer un compromis cognitif entre les objectifs à atteindre, les risques d'erreurs et la contrôle de la fatigue ou du stress lié à la réalisation du travail. L'adaptation à la complexité des situations repose sur la gestion d'une prise de risque constante pour réaliser la tâche à un coût cognitif acceptable. L'opérateur gère en permanence son activité pour dégager des marges d'adaptation qui lorsqu'elles sont dépassées, sont sources de perte de contrôle de la situation ou d'erreur. Mais comme le décrit Reason (16), en raison de leurs natures heuristiques, les compromis peuvent générer une performance qui sans être optimale est acceptable, voire générer des erreurs lorsque les compromis ne sont pas adaptés aux situations rencontrées. Dans ce contexte, on peut envisager l'aide comme un outil d'aide à la gestion du compromis cognitif et à la préservation des marges d'adaptation. L'aide n'est plus une "prothèse cognitive" qui supplée aux points faibles de l'opérateur. Il faut faire comprendre à l'opérateur un point de vue ou un conseil qu'il connaît mais auquel il n'a pas pensé. L'aide est alors une véritable aide à la compréhension, à l'anticipation et à la prise de décision. La notion d'aide se rapproche ainsi de celle d'assistance dans la mesure où elle est en permanence "près" de l'opérateur, c'est-à-dire proche de ses raisonnements. On ne considère plus l'aide à travers l'allocation de fonctions mais comme un système coopératif.

3. A LA BASE DE L'AIDE : L'ACTIVITE DU PILOTE

Concevoir une aide ne peut s'envisager que si l'on a clairement identifié les enjeux cognitifs du pilote, c'est-à-dire les éléments qui vont participer au réglage du compromis cognitif et des marges d'adaptation. Les travaux que nous avons menés sur l'activité de pilotage à partir d'observations en vol et en simulateur, et sur la base d'entretiens avec les équipages ont permis de décrire les grandes lignes d'un modèle du fonctionnement cognitif du pilote (17,18). Ces caractéristiques ne sont pas spécifiques à l'aéronautique de combat et peuvent se rencontrer dans d'autres situations de contrôle de processus dynamique et complexe. Dans le cadre de la conception d'une aide coopérative, il est important de prendre en compte les points suivants :

- Pour maîtriser la complexité des situations de travail dynamiques, la nature de l'activité des pilotes est essentiellement anticipative. L'anticipation permet de ne pas être surpris par un événement et de devenir réactif, mode de fonctionnement pour lequel l'homme n'est pas particulièrement doué, ce que proposent bien souvent les aides "intelligentes" existantes. L'anticipation permet d'éviter les situations à problème en changeant le cours de la tâche pour rester dans ce que l'on sait faire et ce que l'on a planifié ;
- La compréhension et la décision sont indissociables du choix de la solution et de la faisabilité de sa réalisation. Cette relation très forte entre décision et action nécessite de faire en permanence des évaluations sur les hypothèses alternatives ;
- Les pilotes gèrent en permanence plusieurs horizons temporels qui peuvent amener à des niveaux de compréhension et de décision différents suivant les objectifs à court ou long terme. Les décisions à court terme ne sont pas toujours les plus adaptées au long terme. Nombres de réactions prennent en compte ce double horizon temporel et s'effectuent en deux temps avec des objectifs différents à chaque fois ;
- Les pilotes fonctionnent à différents niveaux de représentation et/ou de contrôle suivant les exigences de la situation et leurs propres connaissances. Une aide doit respecter au mieux ses niveaux de fonctionnement. Hollnagel (19) décrit ainsi 4 niveaux de contrôle de l'activité : désorganisé, opportuniste, tactique et stratégique.
- Le fonctionnement des pilotes est régi par un principe d'économie qui vise d'une part, à rester dans une zone de confort pour ne pas être en permanence au maximum de ses capacités, ce qui serait générateur de fatigue et d'autre part, à garder en réserve une capacité d'intervention pour faire face aux événements non planifiés. La conséquence du principe d'économie est que les pilotes peuvent admettre de comprendre superficiellement un aspect de la situation qu'ils jugent non prioritaire voire de ne pas le comprendre du tout lorsqu'ils le considèrent comme peu important. Cela s'oppose à une vision d'un pilote qui doit tout percevoir, tout comprendre avant de décider, ce qui est de par son coût cognitif peu compatible avec les exigences des situations rencontrées ;
- Pour rester dans un registre de fonctionnement compatible avec la sauvegarde de

marges d'adaptations, le pilote accepte en permanence un niveau de risque. Cette prise de risque s'effectue par une réduction de la complexité, une conduite par anticipation et une économie des ressources faisant préférer (quand cela est possible) un niveau de conduite automatique à un niveau de conduite plus réfléchi. L'évaluation du risque par le pilote s'effectue à deux niveaux : le risque externe qui correspond au risque objectif et le risque interne qui représente le sentiment qu'a le pilote de maîtriser ou non la situation. Le sentiment de risque élevé apparaît de façon préférentielle lorsque le risque interne est élevé. Dans ce cas, le pilote abaisse le niveau de risque en préférant abaisser le risque interne aux dépens du risque externe. Cela explique l'échec de nombreuses aides qui basent leur assistance sur le risque externe.

- La récupération des erreurs par le pilote est un mécanisme important de régulation de son activité et de fiabilité humaine. Les meilleurs pilotes sont ceux qui font le moins d'erreurs mais aussi ceux qui savent détecter et récupérer les erreurs commises. Cette récupération n'est possible que si le pilote dispose de marges cognitives suffisantes pour effectuer cette récupération. Par ailleurs, les erreurs renvoient au pilote une image de son propre fonctionnement qui lui permet en retour de mieux régler le compromis cognitif en termes de risque-performance.

4. LE PROGRAMME COPILOTE ELECTRONIQUE

La philosophie du "copilote électronique" est de proposer au pilote une assistance tout comme pourrait le faire un membre d'équipage assis à côté de lui dans le cockpit, d'où son nom. Cette assistance a pour objectifs :

- De ne pas se priver des défenses naturelles du pilote et de ne pas les contrarier ;
- De permettre au pilote de régler son compromis cognitif en lui laissant le contrôle de la situation et de la prise de risques, tout en favorisant la visibilité de ses actions et des actions des systèmes.

Le Copilote Electronique est un système à base de connaissances expertes utilisant les techniques de l'intelligence artificielle. Les premières phases du programme avaient pour objectif de démontrer la faisabilité et la pertinence d'une telle assistance et ont abouti à la réalisation d'une maquette de démonstration sans contrainte "temps réel". L'originalité de cette étude a été d'intégrer dès les phases initiales de la conception des recommandations "facteurs humains" pour la définition des fonctionnalités et de l'architecture de l'aide.

"Copilote électronique" est une aide globale qui intègre l'ensemble des éléments de la mission : le pilote, l'aéronef, l'environnement tactique et la cadre de mission (Figure 1). Ce choix résulte des études préparatoires qui avaient montré que la mission est un tout pour le pilote et qu'il n'est pas possible d'isoler différents objets si l'on veut respecter la gestion des compromis cognitifs. En conséquence, on ne peut envisager la gestion tactique sans prendre en compte les contraintes imposées par d'autres objets comme la navigation ou l'état de la cellule et des systèmes.

Les informations disponibles dans l'aéronef (base de données, capteurs, calculateurs, actions pilote, états des systèmes) permettent de disposer des paramètres d'où sont inférées les informations symboliques propres à chaque composante fonctionnelle. Une étape intégrative gère les différentes contraintes propres à chaque composante en adéquation avec un modèle de reconnaissance des intentions du pilote. Les conseils et analyses élaborés sont alors dépendants de l'analyse contextuelle et des compromis cognitifs du pilote. La dernière étape est celle de l'interface homme-machine.

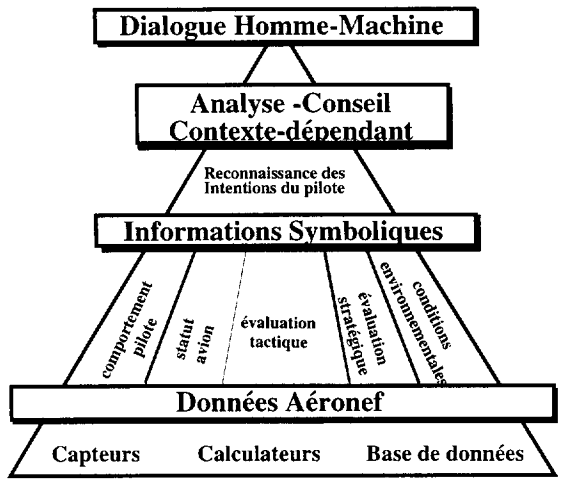

Figure 1. Architecture du Copilote Electronique

4.1. Les principes ergonomiques

L'aide doit répondre à 4 principes ergonomiques pour être en adéquation avec le fonctionnement cognitif du pilote (20) :

- Donner au pilote un niveau de compréhension qui lui permet de comprendre mais aussi de critiquer les propositions émises par l'aide. Derrière cette recommandation apparaît la crainte pour le pilote d'une solution "magique" tombée du ciel dont il ne verrait pas immédiatement les tenants et les aboutissants. Accepter une solution magique, c'est donner la totale main mise de l'aide sur le pilote, chose qui n'est pas acceptable au regard des enjeux sous-jacents. On identifie 4 niveaux de compréhension pour garantir le couplage de l'aide : comprendre la proposition, être capable de l'évaluer, comprendre comment le système l'a élaborée et, être capable de la mettre en œuvre.

C'est à partir de ces niveaux de compréhension que le pilote pourra se construire une représentation mentale des compétences de l'aide. L'intérêt de ces niveaux de compréhension est naturellement de maintenir l'opérateur dans la boucle de contrôle de la situation et de lui permettre d'avoir confiance dans l'aide. Dans ce but, Billings et Woods (21) vont jusqu'à préconiser que l'assistance puisse communiquer à l'opérateur ses intentions et ce d'autant plus que les enjeux sont élevés. Le fonctionnement de l'aide doit pouvoir être prédit par l'opérateur pour que ce dernier l'utilise au mieux ;

- L'aide doit prendre en compte les variabilités interindividuelles. L'analyse et/ou la solution de pilotes expérimentés ne sont pas forcément les mêmes que celles de pilotes tout juste qualifiés. Des différences existent dans la disponibilité en mémoire des informations pour comparer les situations rencontrées aux situations vécues mais aussi dans la capacité à disposer d'habiletés sensori-motrices et cognitives pour réaliser des solutions envisagées ;

- La cohérence de l'expertise est un point essentiel pour l'élaboration de la confiance. Cette recommandation s'oppose aux expertises "patchwork" que l'on rencontre dans beaucoup de systèmes experts. Il est important que l'expertise ne soit pas un amalgame d'expertise qui ne corresponde à aucune expertise humaine. Le pilote attend d'une aide un fonctionnement cohérent c'est-à-dire prédictible et sur lequel il pourra compter : savoir que le système lui fera penser à une analyse ou à une solution à laquelle il n'aura pas pensé, mais qui est compatible avec ses savoirs et savoir-faire ;

- Adapter le conseil et le dialogue homme-machine aux capacités de l'opérateur en fonction des exigences de la situation. Plusieurs niveaux d'interaction peuvent être décrits allant d'interactions directives tant d'un point de vue sémantique que syntaxique dans les situations d'urgence à faible délai temporel, aux interactions plus élaborées lorsque les marges temporelles sont plus importantes.

Ces exigences ergonomiques ont 2 conséquences pour la réalisation du Copilote Electronique :

- Pour être proche des pilotes, les aides doivent intégrer dans leur architecture les spécificités du fonctionnement cognitif des pilotes et non plus se contenter d'une ressemblance de "surface" au niveau des interfaces ;

- La programmation des aides ne peut se faire qu'en intégrant de l'expertise humaine sous la forme de bases de connaissances.

4.2. Les actions facteurs humains

A côté de la définition de ces principes ergonomiques, 4 actions facteurs humains ont été conduites : définition des fonctionnalités de l'aide, constitution de la base de connaissances, définition des principes de dialogue homme-machine et évaluation du concept "copilote électronique".

Les 2 premières actions se sont construites autour du recueil de l'expertise opérationnelle. Une méthode d'extraction et de formalisation commune aux différents partenaires de l'étude a été élaborée. L'objectif de cette méthode était de recueillir de façon exhaustive auprès de pilotes opérationnels en escadron de chasse une expertise cohérente sur les savoirs et savoir-faire en usage afin de constituer la base de connaissances du Copilote Electronique. Pour favoriser la verbalisation des connaissances, des entretiens construits autour de simulations papier-crayon ont été menés. Une extraction des connaissances en profondeur avec 2 pilotes (l'un de Défense Aérienne, l'autre de Pénétration Basse Altitude) a été préférée à une approche multi-experts. Les verbalisations recueillies, environ 50 heures d'entretien avec chaque pilote, ont été transcrites sur papier avant d'être formalisées. Le formalisme, spécialement développé pour l'étude ainsi qu'un outil de formalisation X-Pert, se décompose en 4 concepts : objets, propriétés, actions et raisonnements. Le formalisme a été conçu pour, d'une part pouvoir représenter l'ensemble des connaissances verbalisées et, d'autre part assurer la cohérence syntaxique, lexicale et sémantique de l'expertise formalisée. L'expertise analysée a permis de dégager les fonctionnalités du "copilote électronique" par rapport aux thématiques que sont la gestion de l'aéronef, le suivi de la mission, les aspects tactiques sol-air et air-air.

L'objet de l'étude n'était pas de définir avec précision une interface mais de faire des recommandations à 2 niveaux (22). Le premier niveau est celui des grands principes d'interaction avec le pilote. C'est ainsi que le "Copilote électronique" est un conseiller qui ne prend en aucune façon le dessus sur le pilote. Le pilote peut ignorer l'assistance, voire l'éteindre s'il la trouve inutile. La pertinence des fonctionnalités proposées dépend fortement de leur contexte d'application. Certaines fonctionnalités peuvent être très utiles au pilote, mais les contraintes de la tâche, comme la pression temporelle, les rendent obsolètes dans certaines phases de vol. L'aide fonctionne en permanence de façon transparente pour le pilote afin d'évaluer les situations sans qu'il n'y ait de dialogue homme-machine. Le dialogue n'est initié que lorsque le pilote demande une évaluation ou un conseil, ou lorsque l'assistance s'aperçoit que les objectifs de sécurité et de performance ne sont plus respectés. Pour des niveaux d'assistance élevés (replanification, hypothèse "what-if"), le dialogue est complexe et ne peut s'envisager qu'avec des moyens de dialogue élaborés (commande vocale, synthèse vocale, etc.). Le second niveau de recommandations a consisté à définir sur la base d'un aéronef existant, les règles précises de dialogue en ce qui concerne les modes d'interaction homme-machine ainsi que la syntaxe et la sémantique du dialogue.

La dernière action était de tirer les enseignements des méthodes utilisées et d'évaluer les différents concepts développés dans le cadre de l'étude. Une maquette de démonstration sans contrainte "temps réel" a été réalisée à la fin de l'étude. Constitué d'un ensemble de 5 stations de travail Unix reliées à un modèle avion et à une interface simplifiée, le démonstrateur a permis de valider les fonctionnalités du copilote électronique sur la base de scénarios réalistes où survenaient des événements imprévus. Les résultats de cette action sont présentés dans le chapitre suivant.

5. ENSEIGNEMENTS DE L'ETUDE "COPILOTE ELECTRONIQUE"

L'intégration précoce des facteurs humains dans le processus de conception d'une assistance et le coût que représente le recueil et l'exploitation de l'expertise opérationnelle apparaissaient de prime abord pour les partenaires industriels comme une contrainte. Il faut reconnaître que les concepts d'une assistance écologique n'ont été intégrés par les industriels qu'après un travail important sur l'expertise opérationnelle pour comprendre les enjeux cognitifs des pilotes et dégager les fonctionnalités potentielles d'une assistance. Mais une fois ce travail effectué, il est rapidement apparu que le contact avec le monde opérationnel a constitué pour les équipes d'intelligence artificielle une véritable stimulation en termes de fonctionnalités proposées et de recherches de solutions techniques. En ce sens, les connaissances acquises par ces équipes tant au niveau des modèles du fonctionnement cognitif des pilotes que des méthodes facteurs humains constituent un plus incontestable pour le développement de systèmes à base d'intelligence artificielle utilisant l'expertise des opérateurs.

Lors de la présentation du démonstrateur aux pilotes, les principales critiques ont porté sur la partie visible de la maquette, c'est-à-dire l'interface. Bien que les contraintes de temps réel ne fissent pas parties de la validation, les temps de réaction du démonstrateur furent eux aussi à l'origine de nombreuses remarques. Rapidement, l'évaluation s'est orientée vers une évaluation technique aux dépens de l'évaluation fonctionnelle souhaitée. Il est alors clairement apparu la difficulté de dissocier dans le cadre de tels développements exploratoires, les concepts des technologies. Cela signifie que pour l'avenir, l'évaluation doit être envisagée avec encore plus d'attention. Les points techniques "bloquants" se doivent d'être identifiés et éventuellement contournés par les procédures de simulation s'ils ne peuvent être résolus.
Au cours de l'évaluation, les fonctionnalités des assistances proposées par le copilote électronique ont été validées par les pilotes. L'évaluation a aussi permis de valider la dynamique et la faisabilité des aides proposées. Des réserves ont cependant été émises sur les aides nécessitant des niveaux de dialogue élevés, mais il faut souligner que la faiblesse de l'interface simulée rendait difficile toute représentation d'un produit final. Les avantages d'une assistance "intelligente" sont apparus surtout pour les situations à faible délai temporel. Il a été communément admis que l'aide ne pouvait pas s'imposer au pilote et qu'il faudrait probablement envisager des niveaux différents d'initiation du dialogue avec le pilote suivant les situations rencontrées. Les raisonnements de l'assistance ainsi que les connaissances utilisées ont été reconnues par les pilotes, validant par là même les méthodes d'extraction et de formalisation de l'expertise. Bien que les avantages d'une telle aide apparaissent comme certains, il est en l'état actuel impossible de les quantifier car :

- L'usage de l'aide génère forcément une charge de travail supplémentaire pour le pilote. Cela signifie que l'évaluation de l'aide ne doit pas être centrée exclusivement sur sa seule utilisation mais qu'elle doit intégrer la situation globale de travail et les résultats attendus sur la performance, la sécurité et surtout le confort "cognitif" du pilote.
- La globalité d'une aide comme le copilote électronique va modifier l'activité du pilote et ses relations avec les systèmes embarqués. Il est donc difficile de comparer les bénéfices d'une telle aide avec des systèmes existants. Une évaluation opérationnelle ne peut s'envisager que par rapport à des objectifs qualitatifs de performance et de sécurité indépendamment des moyens pour y arriver.
- Le copilote électronique est une aide dynamique et adaptative tout au long de la mission. Son évaluation finale ne peut se faire que par une mise en situation la plus proche possible d'un contexte réel de mission.

L'utilisation de connaissances opérationnelles dans des systèmes mettant directement en jeu, la performance et la sécurité des équipages pose le problème de la validité de l'expertise. En effet, la validité de l'expertise est limitée dans le temps. Les systèmes de navigation et d'armement ainsi que les capteurs évoluent, les tactiques évoluent en fonction de l'évolution des matériels adverses, les cadres tactiques changent d'un terrain opérationnel à l'autre, les solutions d'aujourd'hui ne seront pas forcément celles de demain. Cette instabilité de l'expertise constitue un des points les plus délicats à gérer. L'expertise est un tout. Le changement d'une connaissance peut avoir des répercussions sur l'ensemble de l'expertise. Les évolutions sont cependant des évolutions de "contenu" et non de "contenant". Les mécaniques de traitement de l'information et de gestion des compromis sont stables et ne remettent pas en cause l'architecture d'un système d'aide. Cependant il est clair qu'une assistance "intelligente" devra être mise à jour régulièrement ou alors être dotée de capacités d'apprentissage. Poursuivre dans cette voie, c'est envisager dès aujourd'hui, des recherches pour développer des systèmes automatiques d'enrichissement et de validation de la base de connaissances.

Une question sous-jacente à la réalisation d'un système potentiellement embarquable est que l'on ne peut ignorer sa certification. Les règles actuelles ne sont pas adaptées aux technologies mettant en jeu des systèmes à base de connaissances opérationnelles. Au-delà de la validité de la base de connaissances, il faut certifier les outils d'intelligence artificielle ainsi que leur utilisation par les personnels navigants. Comment certifier un système dont l'optimalité n'est pas de trouver la meilleure solution mais d'aider le pilote à trouver une solution qu'il saura réaliser et qui lui permettra de remplir sa mission en toute sécurité ? Ces questions sont ouvertes et devront être abordées dans un futur proche.

5. CONCLUSION

Le programme copilote électronique est une première tentative pour apporter une aide coopérative à des pilotes d'avion d'armes. La nécessité de laisser le pilote dans la "boucle" et de l'assister afin d'optimiser ses savoirs et savoir-faire tout en lui laissant une totale gestion de la situation constituent les points forts de l'aide proposée. Réalisé sur 3 ans, le programme a eu comme originalité d'intégrer dès les phases initiales des recommandations facteurs humains provenant de l'analyse de l'activité des pilotes de combat. Associant les techniques de l'intelligence artificielle, le copilote électronique est un système à base de connaissances expertes. Les méthodes développées pour élaborer la base de connaissances et définir les fonctionnalités de l'aide ont été validées. Le démonstrateur présenté à l'issue de l'étude permet de tirer les premiers enseignements. Le programme a permis de valider les assistances proposées ainsi que leurs faisabilités. Si les concepts ont pu être validés, il est certain que les bénéfices d'une telle aide sont encore difficiles à évaluer. Cela ne pourra être envisagé que dans des développements ultérieurs si l'on prend soin de lever les contraintes d'interface et de temps réel.

Malgré ces limitations, un programme comme celui du copilote électronique a permis de développer un savoir-faire "facteurs humains" et industriel qui peut être utilisé pour des applications moins ambitieuses à base de connaissances expertes. Il a surtout permis, même si certaines questions ne sont pas encore résolues, d'ouvrir la porte vers de nouveaux types d'aides qui seront peut-être les seules solutions pour vraiment laisser à l'opérateur humain l'entière responsabilité des décisions prises dans les futurs systèmes complexes.

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Detecting usability problems with eye tracking in airborne battle management support

Frank Ole Flemisch
Reiner Onken
Universität der Bundeswehr München
Werner-Heisenberg-Weg 39, D 85577 Neubiberg / Germany
Tel. –49-89-6004-2139 or -3452
frank.flemisch@unibw-muenchen.de reiner.onken@unibw-muenchen.de

The challenge: More information, still for humans

Information is a key element for success or failure on future battlefields. Continuous advances in information technology and battle management systems, especially growing computer capacity and interoperability promise to provide comprehensive tactical situation awareness down to unit level, thereby improving mobility, survivability and sustainability of today's weapon systems.
However increased availability of information in the computerized support systems does not automatically lead to increased usability. It rather may lead to information proliferation, hidden information and pertinent problems regarding operator information processing. These problems even grow under time pressure in a stressful environment. Are these problems unavoidable? Or is there a solution to handle the overwhelming amount of information which tomorrows battle management systems and personal have to work on?

In aviation there were tremendous technological efforts during the last twenty years to answer similar questions through increase of automation like the introduction of flight management systems or fully computerized „glass cockpits". Again, to the surprise of many people, the relative safety did not increase, but remained almost constant [Billings 1997].

The upcoming solution: Cognitive Automation and Assistant Systems

These problems led to discussions and doubts about the benefit of automation on the one hand, and research in favor of "cognitive automation" on the other hand. As opposed to increased conventional automation in the sense as mentioned above, **cognitive automation** is based on cognitive engineering (e.g. [Rasmussen et.al. 1994]) and more adapted to interact with human cognition [Onken 1998]. This gives the chance to handle more information in the cockpit without decreasing usability.

Prototypes of cognitive automation in aviation are the Cockpit ASsistant SYstem CASSY for civil IFR, flight tested in 1994, and CAMA, the Crew Assistant Military Aircraft, developed together with DASA, DLR , ESG and the University of Armed Forces. Simulator trials were conducted in 1998, flight tests are scheduled for 2000, e.g. [Lenz & Onken 2000] in this proceeding.

But: How can we be sure that no new problems will arise with cognitive automation?

Undoubted, conventional automation was motivated by positive intentions. One major intent was the reduction of workload. The effect was so enormous that, as a result, we face now a "pilot-out-of -the-loop" problem, e.g. [Endsley &Kiris 1995], the "ironies of automation" [Bainbridge 1987] and operators speaking of "99% boring, 1% panic" [Kraiss 1994].

How can we be sure that cognitive automation solves problems but does not raise new problems? If we can not be sure, how can we learn from the lessons and implement ergonomics / human factors right from the start of the development cycle?

Ergonomics / human factors offer a wide range of methods for detection and handling of usability problems. On the other hand, even well experienced concepts like e.g. workload more often fail to reliably describe the problems, especially with increasing technical complexity or „self animated" machines [Sarter & Woods 1994]. How can we implement newer concepts like usability [Nielsen 1993] or situation awareness [Endsley 1995], how can we detect problems like cognitive fixation or dangerous attention distribution?
How can we meet the often different demands of our target groups such as engineers, managers, scientists and operators?
How can we bridge the gap between the diametrical poles "subjective / objective", "intuitive / analytical", "global / detailed" or "scientifically exact / efficient" in order not only to detect but to solve usability problems?

Paper presented at the RTO HFM Symposium on "Usability of Information in Battle Management Operations", held in Oslo, Norway, 10-13 April 2000, and published in RTO MP-57.

A prototype for integrated usability testing: caSBAro

As an answer to these needs a new kind of usability testing tool, caSBAro, was developed in parallel with CAMA. The acronym stands for:

c omputer	supports not replaces human
a ided	factors analysis
S ituation and	analysis of behavior cannot
B ehavior	be done without analyzing the
A nalysis	underlying situation
r eplay and	the record can be fully replayed in a flight simulator
o nline	all caSBAro analysis modules must be capable to work in realtime for the future option to plug them into the assistant system

Figure 1 shows the structure of caSBAro: a generic flight simulator, eye- and headtracker, digital videodisc system and recording / visualization / analysis of man- and machine behavior.

One core element of caSBAro is the sharpening of our best usability measuring tools, our pilots, by offering them a full mission replay in the simulator including the eye tracking records. This gives engineers, managers and operators the platform for a very detailed debriefing without memory effects, an intuitive access to objective data analyzable down to the byte and eyeblink level [Flemisch & Onken 1999].
Another core element of caSBAro and focus of this paper is the analysis of the operators interaction resources, especially the distribution of the visual resource in the cockpit. This gives an almost direct access to the visual part of the human bottleneck and usability problems like information overload or dangerous attention distribution.

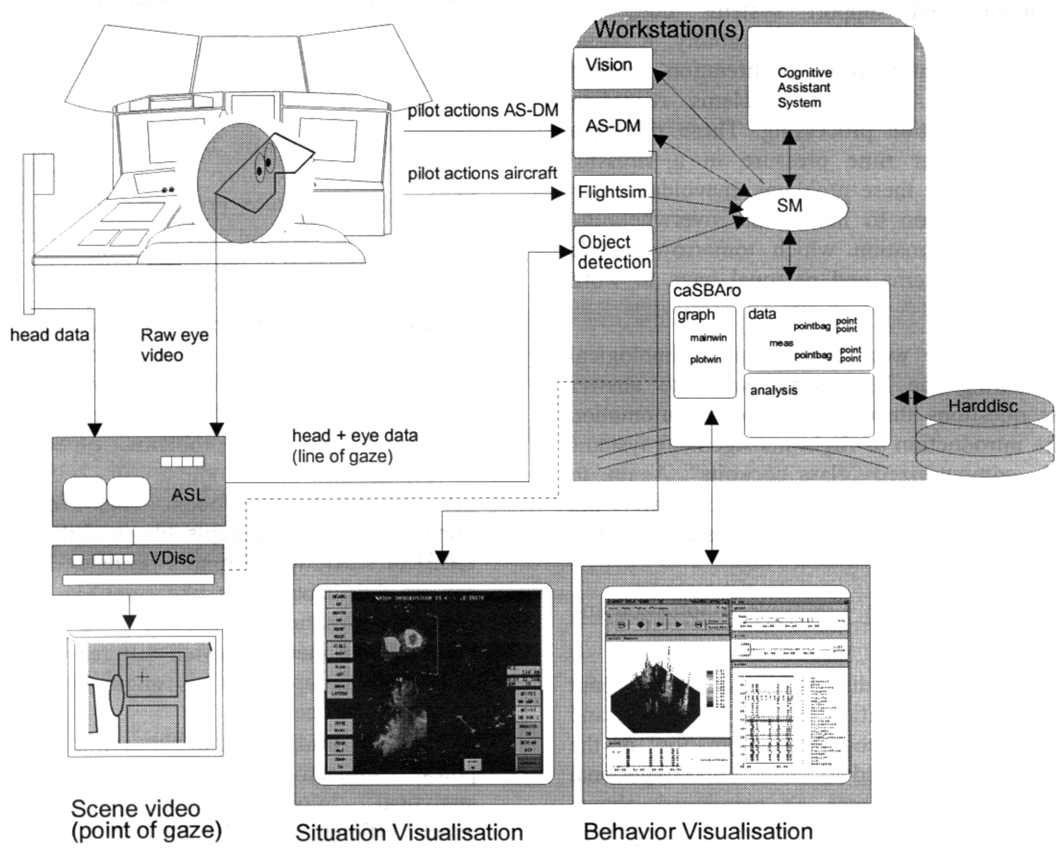


Figure 1: caSBAro

Experimental series on "variation of technical support for manual flying and navigation"

The main objectives for the following series of generic simulator experiments (or better: quasi experiments in the rigorous sense of classical experimental psychology) were:

- estimation of the method's overall sensivity for the visual resource,
- estimation of the method's potential in the ergonomical toolbox, compared to the classical methods "subjective workload" and "objective performance",
- exploration of relationship between different technical supports and their effects on the operator's visual resource in order to improve the assistant system CAMA.

The subjects were 6 military pilots of a German Tactical Air Transport Wing (LTG61 Landsberg), aged 30 –41 (average34) with a experience of 800 – 6000 (average 2700) flight hours on several aircraft types, especially the two engine transport aircraft C-160 "Transall". The experiments were embedded into a 2 days / pilot simulation campaign.

The task performed by the pilots consisted of a combination of two subtasks, a tracking subtask with higher frequency (manual low level flight of a preplanned minimum risk route), and a low frequency supervision / navigation subtask. Each subtask was supported by different technical means.

On the one hand this prototype combination of subtasks is quite relevant for the aviation domain, on the other hand it promised to be prototypical enough to allow a transfer of experience into other domains.

The scenario consisted of a preplanned low level minimum risk route with about 7min flight time in a hilly area (Black Forest), a dynamic threat theater with simulated hostile SAM-stations (Surface-to-Air Missiles) and an ACO (Airspace Control Order) with egress corridors.

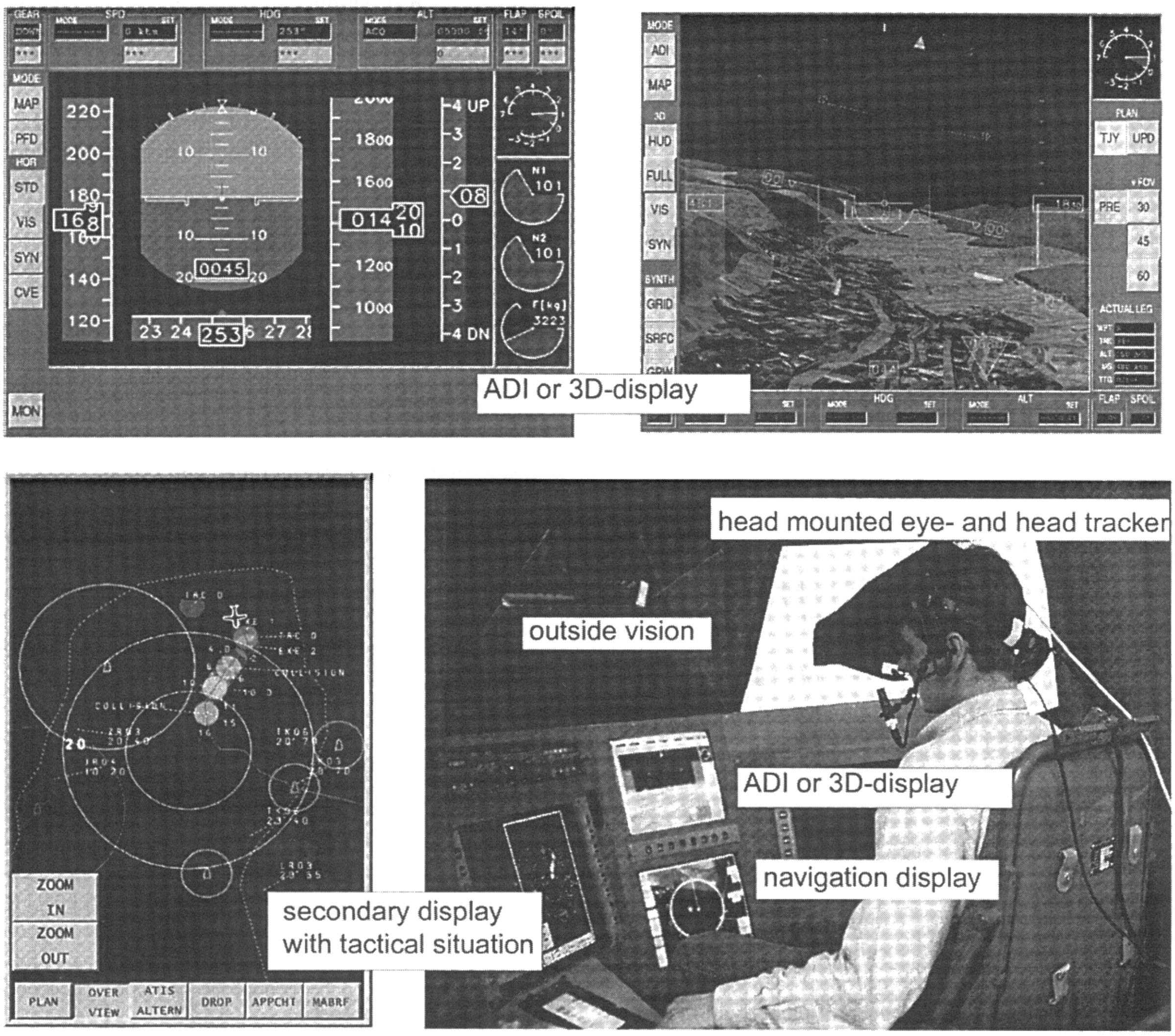


Figure 2: simulator with displays and eye tracking equipement

The subtask F "Manual Flight" demanded flying of the minimum risk route, which remained constant through all experiments, under VFR-conditions (Visual Flight Rules) and "as accurately, fast and, most important, safely as possible". The technical support for this subtask was varied as follows:
ADI: Classical combination of cockpit instruments with artificial horizon, speed, altitude, radar altitude etc. as in state of the art civil aircraft glass cockpit aircraft (as shown in figure 2).

3D: newly developed flight guidance display with three-dimensional dynamic picture of terrain elevation, terrain features and a "tunnel in the sky" of the minimum risk route (as shown in figure 2), (by ESG, see also [Schulte & Stütz 1998]).

3DADI: newly developed combination of ADI and 3D, much smaller 3D-display area.

Auto: no manual but automated following of the minimum risk route, [Bamberger & Lenz 1998].

The subtask N "Navigation" consisted of

1. Monitoring of the tactical situation on the secondary display with regard to changes.
2. In case of changes: decision whether own route or egress corridor is endangered, callout ("threat factor / no factor").
3. If route is endangered: choice of alternative egress corridor, callout of choice, and
4. finally replanning by selecting the alternative corridor on the Secondary display (touchscreen), then selecting button "Replan via" on the Navigational Display.

After that the replanning sequence was terminated, the original minimum risk route remained constant during all experiments.

The technical support for this subtask was varied as follows:

No support: "only" visualization of the tactical situation on the Secondary Display.

Highlighting: highlighting of changes by different color and blinking symbols.

Callout: (in addition to highlighting) a speech output "tactical situation changed".

Proposal: (in addition to highlighting and callout) a machine generated solution by speech output, .e.g. "replan via corridor TK05", highlighting of the alternate corridor and textual feedback on the navigation display.

Simplified activation: (in addition to all support mentioned above) the simple activation of a proposal by selecting a "Roger Do It" button or alternatively by a speech input "roger do it".

Variation and combination of subtasks and support:

Comparison I (E_1 – E_4) investigates subtask F "manual flight" with different technical support, but with no navigation (See also table 1).

Comparison II (E_5 – E_9) addresses the navigational subtask N with different technical support, combined with a pseudo flight task "supervision of automated low level flight". These conditions are comparable to those of a PNF (Pilot Non Flying) busy with a navigational task.

Comparison III (E_15, E_12, E_14, E_11) deals with the combinations of the two subtasks with none or complete support. The idea was that extreme combination of support would also generate extreme behavior and would therefore stretch out the behavioral spectrum in a manner that in between, nonextreme combinations can be derived at least qualitatively by interpolation of extreme combinations without being measured explicitly. The simple but striking reason behind this is the limited maximum time for the experiments due to the weight and pertinent discomfort of the head mounted equipment.

To minimize effects of order of the test runs, they were not conducted in logical order, but were, after placing the order-critical experiments (see chapter collision aircraft), varied according to a replicated Latin square design (see also [Johannsen & Rouse 1983]).

			subtask F „manual flight“			
			autopilot	flight guidance display		
				ADI	3D	3D-ADI
subtask N „Navigation“	no Nav.	**Comparison I →**	E_4	E_1	E_2	E_3
	support	display only	E_5	E_15	E_12	
		+ highlighting	E_6			
		+ callout	E_7	**Comparison III**		
		+ proposal	E_8			
		+ simplified activation	E_9	E_11	E_14	
			Comparison II			

Table 1: Variation of technical support, combination of subtasks

Eye tracking data

Figures 3 – 5 represent the distribution of the visual resource across the visual workspace for the specific subtask / support combination, averaged over all pilots and flighttime. The lighter the areas are, the more fixation time (in this case corresponding to visual attention) pilots spent on that particular spot (excluding warm up phase, exponentially accumulated fixation time, shifted to positive values, standardized to volume integral and projected into 2D, graphical representation by caSBAro-XRT, [Morawski 1999]).
The white %-numbers represent the average percentage of visual attention on the specific region of interest (displays, outside vision)

Subjective workload with SWAT rating

In order to allow comparison of eye tracking with classical approaches, the subjective mental workload of the pilots was measured with the SWAT method (Subjective Workload Asessment Technique). According to this method, mental workload contains three components, time pressure T, mental effort E and stress S in three stages, low 1, medium 2 and high 3.
The TES-triple in figures 3 –5 represent the pilots' median postflight estimation of subjective workload.
W represents the mean value of the conjoint subjective workload. This "conjoint scaling" method also takes into account interpersonal differences in the relative importance of T, E and S. Part of this method is that pilots sort the 27 possible SWAT-combinations in order of relevance before the experiments [Nygren 1991].

Performance P_F for subtask F "Manual Flight"

As the above mentioned subjective workload is only sensitive for the overall task combination, the relationship between technical support and specific subtask must be evaluated by subtask sensitive methods. Subjective methods, e.g. Cooper-Harper-Scale, would also be usable here, but because of the caSBAro capability for recording aircraft parameters, the calculation of a "mean distance to a specified track" d_m as most frequently used method for objective performance assessment can easily be done.
Mean speed ias_m helps to detect potential speed accuracy tradeoffs.

Performance P_N for subtask N "Navigation"

Like for P_F, speed accuracy tradeoffs also have to be controlled for P_N. This is done by two values representing time and accuracy: overall time for solving a conflict and percentage of correct / successful reaction.

Moreover this subtask can be structured with respect to the different stages of human information processing, e.g. according to [Wickens 1992]:

1. **perception**, here detection (and callout) of a potential conflict (step 1 and 2 of the description for subtask N above).
2. decision and response **selection**, here selection of a alternative egress corridor (and callout).
3. response **execution**, here activation of a replanning process.

Because a specific technical support can have different effects on different stages, average time and quality percentage was calculated for each specific stage. In order to highlight the overall effect, only correct reaction were accumulated over the three stages. Table 2 provides an example referring to figure 4 E_5:

	Single stage performance	Accumulated overall performance	time
perception		82%	3.7s
selection	88% + 2.0s	72%	5.7s
execution	60% + 3.6s	**43%**	**9.3s**

Table 2: objective performance of subtask N, example from figure 4, E_5

This means that within this subtask/support combination, averaged over 6 pilots, 82% of all navigational conflicts (changes of tactical situation that endangered the preplanned route) were detected and called out by the pilots after 3.7 seconds. 2 seconds later 88% of these conflicts were also solved (and the solution called out) correctly, 3.6 seconds later 60% of these solutions were also executed correctly, so that 43 % of all conflicts were solved correctly after 9.3 seconds, 57% were incompletely replaced by a subsequent conflict or failed at one or the other stage of the pilot's information processing.

Comparison I: Variation of subtask F "Manual Flight", no Navigation

Comparison I looks at the isolated subtask F "Manual Flight" with different flight guidance support ADI, 3D, 3DADI and automatic flight. In figure 3 e.g. "P_F+" stands for an improvement in flight performance, "W =" for an almost constant subjective workload. Black arrows show a virtual flow of visual attention between two configurations.

E_1 ADI represents the classical low level flight under VFR conditions (Visual Flight Rules) and with state of the art displays: Subjective conjoint workload W is average with 42%. This subtask and configuration is the daily but nevertheless not easy job of these pilots. Visual attention is mostly (56%) directed to the outside vision, where e.g. hill ridges are fixated in order to avoid terrain collisions. The visual scanning pattern of the ADI is characterized by a classical "basic T", a repetitive change between speed, artificial horizon and altitude / radar altitude / variometer. Short gazes downwards to the Navigational Display are used to detect deviations from the minimum risk route and to perform medium-term orientation ("ok, after the next ridge right into the valley, then one mile straight on, uups...").

E_2 3D is the same flight with 3D-display: Visual attention is attracted by the integrated information of terrain, aircraft attitude and minimum risk route on the 3D-display. This limited visual resource is withdrawn mostly from the outside vision and partly from the navigational display. Some pilots urge themselves to check the outside environment more frequently (max. 35%), others just abandon this source of information (min. 4%). Flight path accuracy as measurement of objective performance is almost 4 times higher than with classical ADI, speed is higher, subjective workload is clearly reduced.

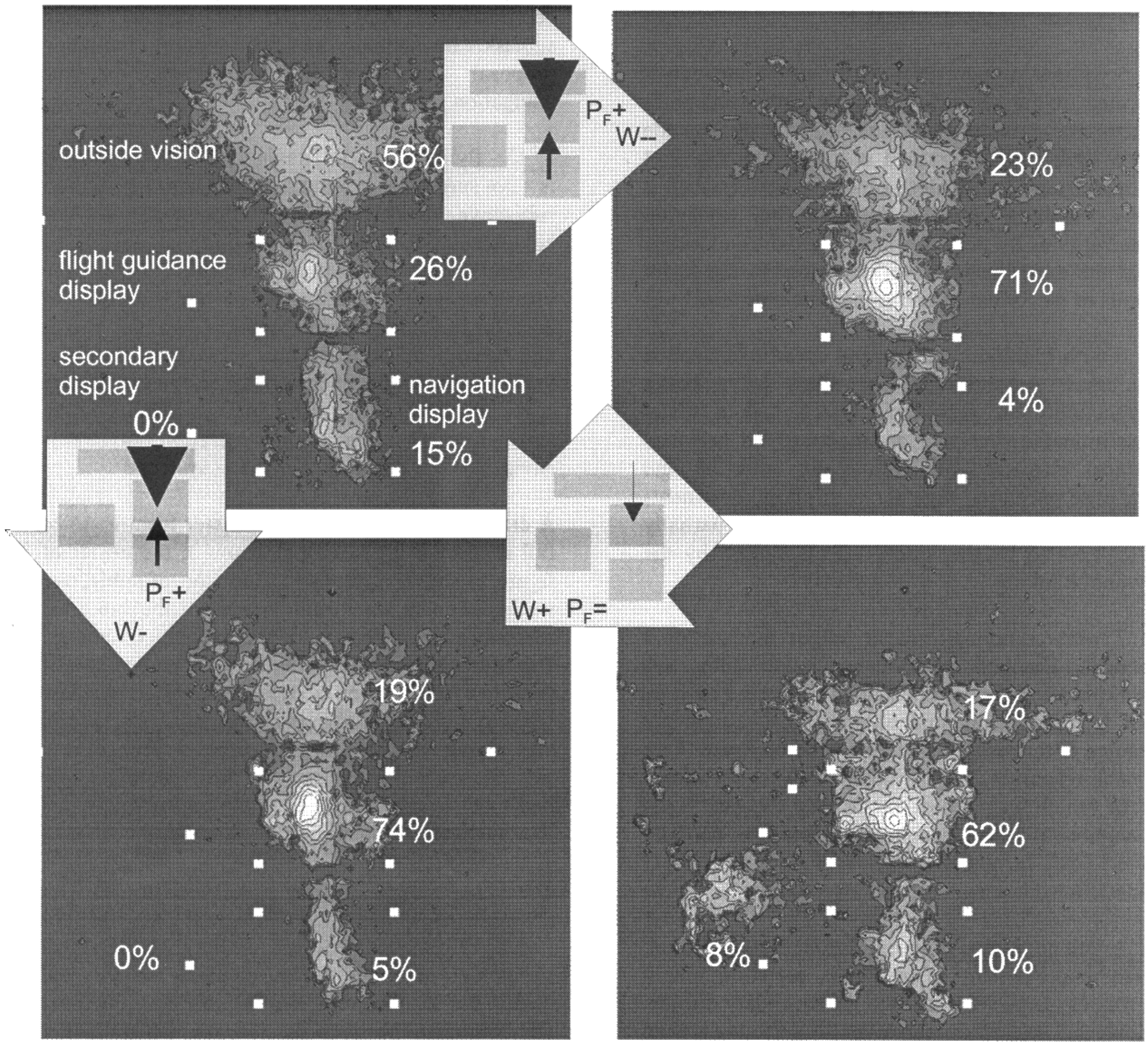
E_3 3DADI is the hybrid of classical ADI and 3D: The concentration effect already observed in E_2 even grows stronger, performance is almost equal, subjective workload is increased due to the small size of the 3D-window, but is still lower than E_1.

E_4 autopilot with pilot as supervisor: Even though the autopilot configuration is quite convenient (lower flight path accuracy and speed as flown by the pilots themselves), subjective workload is higher than in e.g. E_2. When asked about these surprising ratings pilots stated a "natural distrust" of automated flight due to lack of experience and short reaction time in case of malfunction.

The automation frees visual resources, which flow into the secondary and the navigational display, nevertheless the overall distribution of visual attention is quite similar to E_2. As e.g. the scanpath theory [Stark & Choi 1996] formulates a strong relationship between observed visual behavior and internal mental representation of a visual task, we can therefore assume that the visual parts of "flying an aircraft" and "supervising a machine flying an aircraft human-like " have quite similar mental representations. This affirms e.g. efforts like [Schulte 1996], who investigated visual behavior of pilots in low level flight by stimulating them with a movielike video replay of a real flight in a simulator with outside view.

E_1 W 42% T 1 E 2 S 2
F: **ADI** d_m 0.118nm ias_m227 knots
N: -

E_2 W 9% T 1 E 1 S 1
F: **3D** d_m 0.028 ias_m255 knots
N: -



E_3 W 21% T 1 E 2 S 2
F: **3DADI** d_m 0.032 ias_m253 knots
N: -

E_4 W 22% T 1 E 2 S 1
F: **Auto** d_m 0.036 ias_m205 knots
N: -

Figure 3: Comparison I, flight with different displays, no navigation

Comparison II: Variation of Navigation, Autopilot

Comparison II (figure 4) investigates the influence of different technical support for subtask N "Navigation" without subtask F.

E_5 without support: 89% of the visual attention is located at the secondary display, only sometimes gazes are moving elsewhere, e.g. to the outside view. Subjective workload is lower than e.g. E_4 (supervision of autopilot), objective performance is only medium mainly because of execution interruptions by new conflicts. This gives evidence that the experiment is working close to the upper limits of performance and is therefor sensitive.

E_6 with highlighting: rate and speed of detection increases. Reasons for that might be a better detectability in peripheral vision and a faster discrimination between endangering and harmless tactical elements. The values for selection and response execution together with pilots' comments could be a hint that the improvement is partially compensated by distracting effects caused by the symbol blinking.

E_7 with additional speech output in case of a tactical change: performance and subjective workload are almost unchanged compared to E_6, but a fundamental quantitative and qualitative change of the visual behavior can be observed: Free visual resources almost doubled. The attentional field, which was almost exclusively focused to the navigational task / secondary display, is partially freed now. In contrast to E_6, the complete right side of outside vision can be covered now.

E_8 with additional proposal for conflict resolution: high improvement of response selection, slight reflux of visual attention into the secondary display. However, regarding the overall performance an almost paradox effect can be observed: Although pilots know the conflict solution much faster than the machine, they tend to wait for the proposal to assure themselves. So they loose precious time for the execution before the next conflict occurs. This effect could of course also happen in reality, but the observed effects on the overall performance can be considered as an artifact caused by the experimental conditions, especially the relative simplicity of the navigational task.

E_9 with simplified activation by "roger do it" button or speech input: The "waiting for the proposal" effect is still observable, but these proposals are activated fast and accurate, so that compared to unsupported E_5 overall time is equal, but quality doubles! Freed visual resources can flow in other information sources.

Comparison III: Extreme combination for flying and navigation

Comparison III (figure 5) investigates the extreme combinations, ADI or 3D for manual flying subtask, no support or full support including proposal and simplified activation for the navigation subtask.

E_15 - flying with ADI, navigation with no support is - not surprising - the experiment with the highest subjective workload. The flying subtask is, compared to E_1 with no navigation, performed without major dropouts, even with 20% of the visual resource withdrawn from this subtask and used for the navigational subtask. Obviously this is not enough to perform this subtask sufficiently, leads to the lowest success of 12% and a SWAT stress value of 3 for all pilots. Remarkable is the still successful rule of prioritization "aviate – navigate – communicate – manage systems"

A closer look at the extreme transfer from E_15 to full support E_14 (diagonal arrow in the center of figure 5) shows a dramatic reduction of subjective workload and a huge improvement of the subtasks' performance, especially for the navigation subtask. Regarding the visual resources, the percentage of the three information sources navigation display, secondary display and outside vision is reduced to a half and focused to the 3D display (triplication). The detailed mechanism of this resource flow becomes transparent by a closer look to the intermediate combinations:

The transfer from E_15 to E_12, ADI to 3D with unsupported navigation, leads to an improvement of flight performance with a concentration of visual resources, flowing from outside vision and navigation display into the 3D display, an effect that can also be seen in Comparison I. Better support for the subtask F does not only improve flying, moreover freed resources can be used for the navigation subtask, visible in a higher percentage of the visual resource allocation in the secondary display and a better performance on all stages of information processing.

Adding the navigation support (E_14) now leads to an acceptable performance of navigation with almost constant flight path accuracy. Simultaneously freed visual resources can be reinvested into the outside vision.
A similar picture can be developed by following the circle counterclockwise from E_15 via E_11 to E_14: additional navigation support in E_11 leads to a higher navigation performance, which reaches not yet the maximum of E_14.

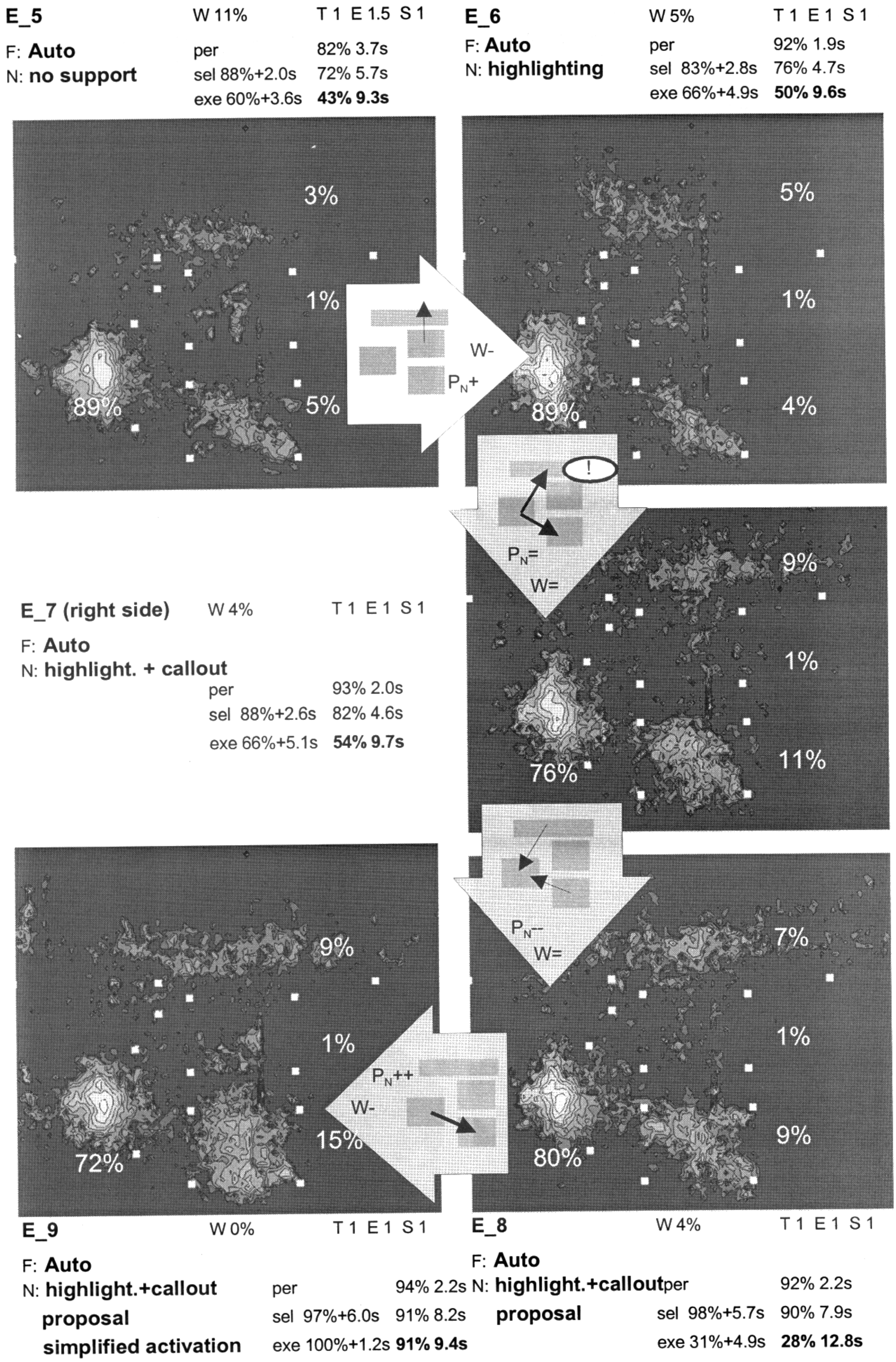


Figure 4: Comparison II, automatic flight with navigational support

Simultaneously freed resources flow back to the subtask F. These resources are reinvested not so much into the outside vision – obviously this percentage is already high enough compared to e.g. E_12 – but more into the ADI.

The transfer from E_11 to E_14 once again shows the effects of the 3D display, improvement of flight quality and concentration of visual resources.

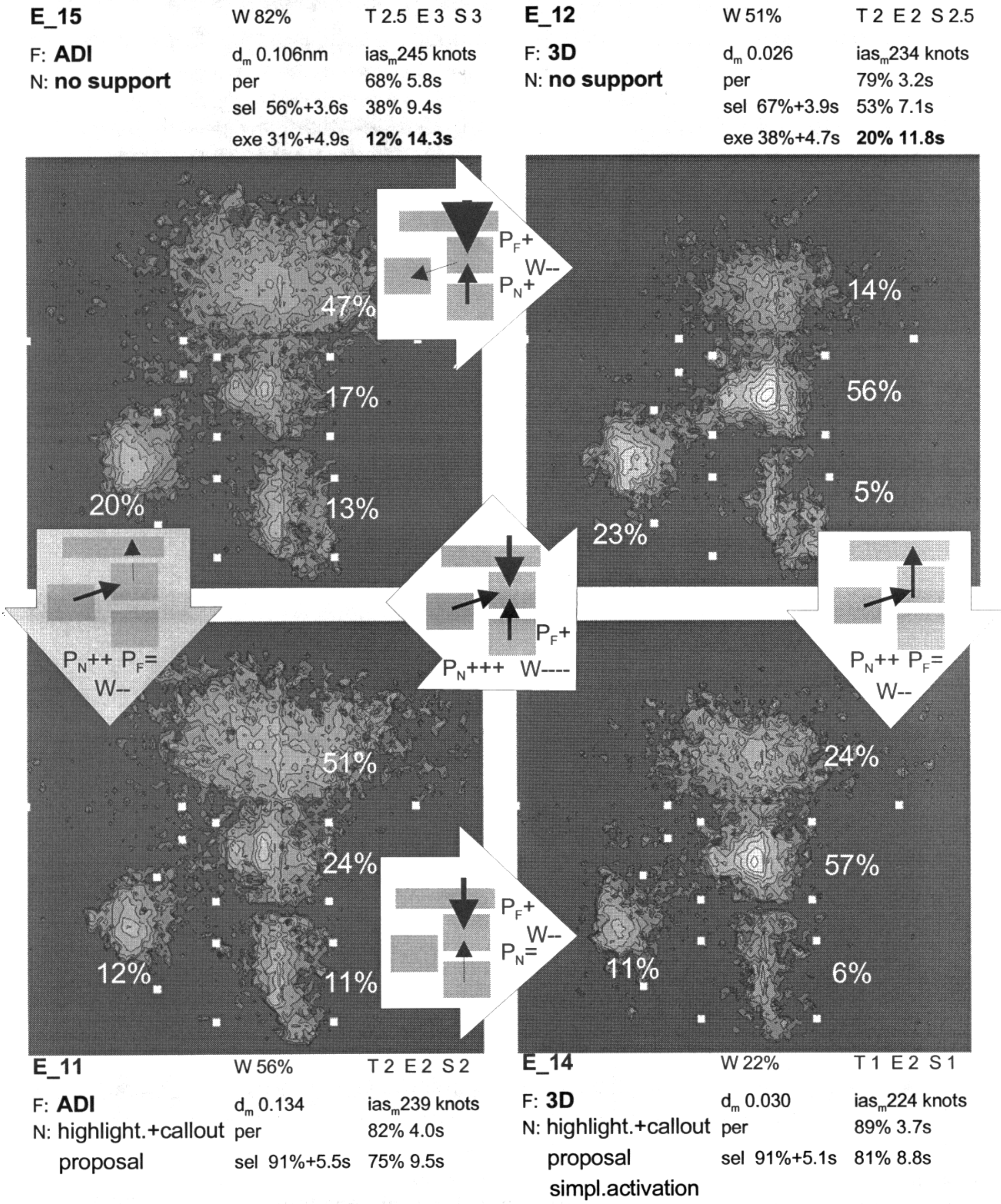


Figure 5: Comparison III, extreme combinations

Test with collision aircraft

The observed concentration of visual resources into the 3D display is not negative by itself, the performance improvements are quite impressing. Nevertheless pilots and evaluators had uneasy feelings after a look at the eye tracking videos and resource distribution. The reason is the - until now unmentioned nevertheless vital - subtask of airspace observation. This subtask has always be performed when flying according to VFR (Visual Flight Rules) in order to avoid collisions with other aircraft.

As missing visual attention is a strong indicator for missing situation awareness, and missing situation awareness is a strong contributing factor for accidents, these distributions for visual attention measured here would be enough reason to take corrective actions. Nevertheless we did an explicit test in the simulator by introducing collision aircraft. They flew along the same minimum risk route just into the opposite direction, with a speed of 200 knots, clearly visible in the outside vision.

According to signal detection theory, e.g. [Wickens 1992], after the detection of the first collision aircraft there would be a strong risk of a complete change of the attention distribution. Therefore this event "detection of collision aircraft" should reasonably happen only once per pilot without giving any hint before.

Because of the statistical difficult low number of test subjects, the pilots were asymmetrically divided into two subgroups, subgroup I with ADI / no navigational support (4 pilots), subgroup II with 3D / no navigational support (2 pilots). At the end of the corresponding flights E_15 and E_12 three successive collision aircraft were simulated. After the first detection, ascertained by callout, avoidance maneuvers or clear hints in the eye movement monitor, the experiment was terminated. The events "aircraft detected" and "aircraft not detected" had the following distribution:

Subgroup	Aircraft detected	Aircraft not detected
I ADI	4	1
II 3D	1	5

The basic hypothesis H_0 states that the two different technical configurations do not produce a different risk of colliding with another aircraft. A Pearson-$\chi 2$ test shows a significant difference with $p_{alpha} = 0.036$, but because the actuarial expectation value per cell of the 4field table is smaller than 5, it is not appropriate in this case. Luckily the side sums are almost equal and due to the experimental design a binomial distribution can be assumed, therefor the "single sided Fisher Yates exact test" can be used. This value, $p_{alpha} = 0.067$, is not significant at the confidence level used for scientific experiments (95%), but due to the lower demands of the usability paradigm, e.g. an appropriate confidence level of 90% suggested by [Nielsen 1993], H_0 can be rejected with "strong tendency to significance".

The direct transfer of this result from the small number to a complete population of pilots is, due to the design of the experiment, still not statistically valid without further control. Theoretically this outcome might have been produced by a completely different visual behavior of the 2 "collision" pilots compared to the 4 "normal" pilots and the total population. But as in E_12, the average percentage of visual attention in the outside vision is 14% for all 6 pilots, compared to a slightly smaller 12.5 % for the two "collision" pilots, there are strong hints that the danger of not detecting collision aircraft is not caused by interpersonal differences but by the configuration of displays.

Discussion of the technical support

Due to the small number of subjects the above mentioned observations and results just have tendency to significance ($p_{alpha} < 0.1$) and therefor - according to classical experimental psychology – want to be used with caution. Considering the lower statistical demands of the usability paradigm, e.g. in [Nielsen 1993], and the early phase of the exploratory process, we can nevertheless discuss the following findings:

Each of the described levels of support for the navigation subtask improves speed and/or quality of performance.
Intelligent highlighting using the situational knowledge of the assistant system improves information perception. Additional acoustic information can solve captivation of the attentional field and therefor avoid blind areas, as E_7 (Comparison II) shows. Negative effects of cluttering other acoustic information sources, which were not investigated here but can be suspected, can probably be avoided by nonvocal, spatial coding of the acoustic signal.

The machine generated proposal for conflict resolution, which was investigated here, is relatively simple due needs to keep the experiment under control. In situation with low workload pilots solve these conflicts much faster. But even with that simplicity, in situations with higher workload, especially with an additional higher frequency subtask which competes for concurrent resources, a computer-generated proposal clearly improves speed and quality of conflict resolution. It is of course mandatory, beside high quality and reliability, that the computer solution is plausible and transparent in order to build up appropriate trust / mistrust and therefor enable successful supervisory control.

The simplified activation of proposals offers an additional speed and quality improvement, which can be used optionally: In situation with sufficient resources, pilots can choose a different, more explicit man machine communication in order to maintain situation and process awareness, in situations with lack of free resources pilots can activate very simply and reliably a solution that is, at least, safe. We call that optional aspect "implicit support of operators' own resource adaptation" or "implicit adaptation". The machine does not explicitly adapt to a low resource situation, but offers implicit means for resource adaptation (see also [McKinley 1985], [Verwey 1990]). Few negative effects like potential risk homeostasis and complacency have been observed. They have to be compensated by e.g. supervised training (e.g. with mission-replay in the simulator).

The 3D display with an information fusion for terrain, flightpath and aircraft's attitude offers benefits, but there can be a problem with the concentration of visual resources toward the head-down displays. This effect, in these experiments, led to a clear lack of situation awareness regarding collision aircraft. The above mentioned simulator test investigates – of course - the configuration without navigation support, which promised to be most sensible for this effect. An influence of the head mounted equipment can not be excluded, the pilots might have been conditioned to a simulator environment where there was no experience with collision aircraft. Moreover this concentration effect will be of quite different impact with a two or three man crew.
Nevertheless it must be assured that the existing risk will be compensated. Only if this proves successful, the observed clear improvement of flight performance can fully exploited. The freed resources can be used to improve other subtasks like navigation, an effect which will be even stronger in degraded visual conditions, which where not investigated, so far.

Discussion: Is eye tracking worthwhile?

Eye movement measurement offers deep insights into man machine interaction and the mental processes of pilots. The analysis of the visual distribution in the cockpit, averaged over pilots and time, illuminates global effects of the visual resource with high qualitative depth and face validity.

Visual attention is a limited resource and has to be scheduled by the pilots to different information sources. Technical means influence this operator's own resource management positively or negatively even to the extreme of total cognitive fixation to one technical subsystem. A direct relationship between the risk of low performance, which can often not directly be measured, and an unfavorable visual distribution, which can be measured, clearly exists and can be used to detect resource based usability problems and avoid fatal results.

But these experiments also show that the methods used are not equally sensitive and reliable for all ergonomical questions. There are quite some examples in the described experiments where only one method succeeded in detecting a specific fact while the others were insensitive. A holistic qualitative picture of a specific man machine interaction seems to get illuminated best with an appropriate combination of methods.

Therefor the analysis of the visual resource is just one additional, but powerful tool in the tool box of ergonomy. Factors like time, personal effort and money will contribute to the decision whether this tool will be used. The ongoing development of smaller and cheaper hardware, the availability of sophisticated analysis software and a caSBAro like high integration of eyetracking into the usability laboratory will make it easier to use this method in the development process.

Conclusion

The benefits of information technology ought to be exploited also for battle management operations, but we know that there might be side effects and new risks like violations of the human limitations of cognition and information processing.

There are methods to control these risks, we have to use these methods right from the beginning of a development process, and we have to improve these methods permanently in order to catch up with the speed of technology.

Even if these methods are no guarantee for ideal information systems, they offer a much better chance for improving usability. If we do not take this chance, we will spend money on new technology, but will loose systems and men instead.

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APPLYING "COLLABORATION" TO UNITED STATES EUROPEAN COMMAND (USEUCOM) MISSION PROCESSES

Mr. Gregory G. Chapin
Senior Systems Engineer
MITRE Corporation European Operations
Geb. 2302, Zi. 109
Patch Kaserne
70569 Stuttgart, Germany
Telephone: +49-711-680-5786
Fax: +49-711-687-7799
Email: gchapin@mitre.org

LCDR Steve Dodd
Deputy Chief of Targets
USEUCOM Intelligence Directorate, Targets Branch
From Dec 1996 to Oct 1999
Telephone: 001-902-427-0550 extension 0154
Fax: 001-902-427-5724
Email: tn22@marlant.hlfx.dnd.ca

Foreword

"[The] ability to reach-back and use capabilities in the continental United States to perform functions formerly accomplished only in the theater of military operations is one of the highlights of operation Allied Force. Such capability improves responsiveness to urgent requirements in a conflict and reduces the amount of equipment and the number of personnel that must be transported to the theater. In short, the capability to integrate our force globally yields significant improvements in our ability to respond to crises, particularly during their initial stages...

Extensive growth in communications capacity enabled an unprecedented degree of reliance on U.S.-based forces to provide direct support for in-theater tasks. Targets in Kosovo and the Federal Republic of Yugoslavia were developed through the concerted effort of numerous agencies in the United States cooperating closely with commands in Europe. Planning and integration of cruise missile attacks by bombers operating from the continental United States and the United Kingdom and by ships and submarines operating in the Mediterranean were closely coordinated by commanders and planners who were widely separated geographically. Bomb damage assessments of strikes made against targets in theater were conducted by agencies and commands located in the United States in close support with efforts by commands in the European theater. This system of using geographically dispersed activities to perform and integrate bomb damage assessment (BDA) became known as federated BDA. Expert personnel located in the United States and Europe performed detailed planning of information operations. Kosovo operations continued a trend of increasing global integration of U.S. forces and commands to support operations in a distant theater.

The European Theater's unprecedented reliance on organizations and personnel in the United States and elsewhere was enabled by advances in information technology. High-capacity communications made possible the exchange of large amounts of data such as high-resolution imagery and secure video teleconferencing. In addition, extensive growth and availability in defense data and communications networks enabled unprecedented coordination by staff members in European commands and supporting commands outside of Europe by secure e-mail. Secure

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high-capacity networks using Web-based technology permitted personnel; engaged in theater to access up-to-date information posted for their use on military Web sites around the world."[1]

This paper describes how collaboration can be applied to mission processes to support deliberate and crisis planning and operations. Operation Allied Force operators stated that proper application of collaboration improved the effectiveness of information processes, improved product quality and benefited federated efforts by geographically separated partners. During Operation Allied Force, USEUCOM operators demonstrated that collaboration can benefit mission effectiveness. Applying collaboration to existing or modified mission processes needs to be continued, refined and expanded to include NATO allies.

This paper serves as a reminder of the most important system component, the military operators, who effectively applied collaboration to benefit mission processes. The assistance of Lt Col Western, LTC Stearns, LCDR Kraft, and SMSgt Schwarting is appreciated. The dedicated efforts of LCDR Dodd as operational advisor and key contributor are also recognized.

Direct comments and questions about this paper to Mr. Greg Chapin.

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LCDR Steve Dodd, USN
LTC Juan Dusmet, Spanish Army, Battlefield Information Collection and Exploitation Systems (BICES)
LCDR Cynthia Gaston, USN, Chief, Multi-National Intelligence Coordination Cell (MNICC)/ Joint Analysis Center Molesworth
Ms. Isma Granger, MITRE
Mr. Jack Hammond, MITRE, (BICES)
Col Uwe Holland, German Air Force, Intelligence, BICES
Maj Pat Johnson, USAF, U.S.JFCOM Cruise Missile Support Activity (CMSA)
LCDR Rob Kraft, USN, USEUCOM, Targets Branch
LtCol Tony Montgomery, USAF, USEUCOM, Deputy Staff Judge Advocate/Chief of Operations Law
Mr. Spurge Norman, MITRE
Ms. Karen Pagel, MITRE
LCDR Doug Peabody, USN, COMSIXTHFLT, TLAM Strike Cell
Mr. Winston Rogers, MITRE, BICES
Ms. Maggie Scheid, MITRE
SMSgt Ron Schwarting, USAF, USEUCOM, Production Branch
LTC Frank Stearns, USA, USEUCOM, Watch Chief
Col Marc Thompson, USAF, USEUCOM, Chief, Production Requirements Division
LtCol Paul Turner, USAF, USEUCOM, Systems Branch, Chief of NATO and Coalition Intelligence Support, Systems, Linked Operations-Intelligence Centers Europe (LOCE)
Ms. Ruth Ann Valentine, MITRE
LtCol Jeff Western, USAF, USEUCOM Chief of Targets

Introduction

This paper describes the United States European Command's (USEUCOM's) application of "collaboration[2]" to mission processes. The main points presented are:

1. USEUCOM is judiciously applying collaboration to benefit mission processes. USEUCOM is:

- Applying collaboration daily to mission processes; not just talking about it
- Supporting operations and contingency planning with collaboration to reduce process timelines and improve product quality; not conducting demonstrations, experiments, or studies
- Collaborating in an operational environment with the associated constraints and security accreditation requirements; not in laboratories or across networks using equipment not representative of USEUCOM's environment
- Benefiting from lessons learned and best practices
- Expanding collaboration when and where it makes sense

According to Operation Allied Force participants, collaboration mitigates the effects of information overload, improves team decision-making, and

[1] Kosovo/Operation Allied Force After-Action Report to Congress, 31 January, 2000, pp. 122-124

[2] "Collaboration" is more than just the technological capabilities (e.g. web-based applications, whiteboard, text chat, and audio). For this paper, collaboration includes:

- Technological capabilities
- Collaborative session techniques
- Concept of operations (e.g., process owners, roles and responsibilities, and procedures)
- Standardized product templates

Attachment 1 describes the primary collaborative techniques and capabilities used at USEUCOM.

synchronizes situational awareness. USEUCOM participants indicate that collaboration is positively impacting mission processes.

2. Operation Allied Force demonstrated the benefits of collaboration and highlighted USEUCOM's operational requirement to collaborate with NATO allies to support operations. As a result, USEUCOM senior leadership is advocating the expansion of collaboration within the intelligence community, including expansion to NATO allies. NATO should consider satisfying the collaboration requirement. First, NATO might consider satisfying this requirement within the targeting community, focusing on target development and nomination, target approval, and Air Tasking Order (ATO) generation and management. Challenges and issues addressed by USEUCOM to satisfy the collaboration requirement are discussed. Like USEUCOM, NATO may encounter some similar and some unique challenges and issues.

3. USEUCOM encountered and addressed several challenges and issues to apply collaboration successfully to mission processes. USEUCOM's lessons learned and best practices are provided for NATO's consideration and potential use.

USEUCOM Experiences Applying Collaboration to Mission Processes

"The command, control, communications, and computer (C4) support to Operation Allied Force was highly successful. Several important communications capabilities saw their first significant combat application: use of Web-based technologies for coordination and information sharing; video teleconferencing for command, control, and coordination; and e-mail for coordination and tasking."[3] This section describes USEUCOM's use of collaboration for combat applications during Operation Allied Force.

USEUCOM is applying collaboration to three mission processes.

- Tomahawk Land Attack Missile (TLAM) Mission Planning
- Final Phase of Fixed Targets Development and Nomination for Approval
- Synchronization and Sharing of Current Intelligence

A summary of each process describes:

- Need and Objective
- Process and Participants
- Approach
- Results

Comments from Operation Allied Force participants on applying collaboration to USEUCOM's mission processes conclude this section.

TLAM Mission Planning

Need and Objective:
Before applying collaboration, COMSIXTHFLT tasked the Cruise Missile Support Activity (CMSA) with Tomahawk Land Attack Missile (TLAM) mission planning using message traffic in sequential fashion. According to COMSIXTHFLT and CMSA participants, the ambiguity and uncertainty inherent in cumbersome, text only message tasking needed to be replaced by a more efficient tasking mechanism and process. CMSA frequently contacted COMSIXTHFLT for additional information or clarifications to satisfy the Mission Planning Requests (MPRs). Participants indicated that this methodology needed modification to improve accuracy, effectiveness, and responsiveness of TLAM strikes.

Process and Participants: TLAM mission planning is the first mission process in USEUCOM to use collaboration actively. The USEUCOM process owner[4] is COMSIXTHFLT TLAM Strike Cell, Plans. Primary participants include:

- COMSIXTHFLT Gaeta, Italy: TLAM Strike Cell, Plans
- U.S. Joint Forces Command (JFCOM) Cruise Missile Support Activity (CMSA) Norfolk, Virginia

Other participants include:

- Headquarters United States European Command (USEUCOM) Stuttgart Germany: Targets, Crisis Action Plans

Approach: COMSIXTHFLT provides targeting and mission information to CMSA by completing a web-based MPR form. CMSA retrieves the MPR from the web and uses the information to work the task. The web-based MPR form with pull down menus improves the communication and coordination process. The selectable menus facilitate tasking and planning by providing a mandatory specific standard list of field declaration options. If necessary, CMSA reviews certain MPR fields with COMSIXTHFLT to obtain clarifications and ensure the tasking is understood. As the tasking organization, COMSIXTHFLT obtains relevant imagery products. COMSIXTHFLT and

[3] Kosovo/Operation Allied Force After-Action Report to Congress, 31 January, 2000, p.26

[4] The process owner is the responsible for creating a group with a mission focus, directing the participants, and controlling collaborative sessions. Collaborative session focus, participant roles and responsibilities, and results are the process owner's responsibility. Reference the operational category of the Lessons Learned and Best Practices from USEUCOM's Collaborative Experiences section for recommended process owner responsibilities.

CMSA use collaboration to simultaneously review and annotate the imagery products. The simultaneous review expedites task completion and synchronizes understanding. CMSA uses the MPR and collaborative session results to fulfill the request by producing the TLAM mission and associated TLAM Target Aimpoint Graphic (TAG).

Results: COMSIXTHFLT and CMSA participants indicated that applying collaboration and using the web-based MPR form improved the TLAM mission planning process. Participants indicated that the modified approach resulted in improved accuracy, effectiveness, and responsiveness of TLAM strikes compared with the former approach. The MPR template assisted in standardizing terminology. Accuracy and completeness in satisfying information requirements improved. TLAM mission planning participants indicated that collaboration removed tasking ambiguity. As a result, participants estimated that response times from mission tasking to planning completion were nearly cut in half. COMSIXTHFLT's and CMSA's continued operational use and advocacy for the web-based MPR form and collaboration appears to be another indication of success.

Final Phase of Fixed Targets Development and Nomination for Approval

"During the course of the campaign, NATO developed mechanisms for delegating target approval authority to military commanders. For selected categories of targets — for example, targets in downtown Belgrade, in Montenegro, or targets likely to involve high collateral damage — NATO reserved approval for higher political authorities. NATO leaders used this mechanism to ensure that member nations were fully cognizant of particularly sensitive military operations, and, thereby, to help sustain the unity of the alliance.

Legal reviews of selected targets were conducted at successive echelons of the chain of command. Targets nominated for approval by SACEUR received legal reviews in the field. Targets nominated that met the criteria requiring NCA approval received detailed legal scrutiny by the Legal Counsel to the Chairman of the Joint Chiefs of Staff and by the DOD General Counsel. Legal reviews involved evaluation of certain targets as valid military targets as governed by applicable principles of the laws and customs of armed conflict."[5] As described below, the USEUCOM targets community used collaboration to support portions of the fixed targets coordination and approval process.

Need and Objective: The extended air campaign against Serbia lasted 78 days and required a more efficient targets development and production process. "During Operation Allied Force, NATO forces conducted over 23,300 strike missions against an array of targets. These strikes were directed at roughly 7,600 target aim points associated with a variety of fixed targets as well as at just over 3,400 flex targets."[6] The USEUCOM Chief of Targets requested that the fixed targets development and nomination process be modified, leveraging collaboration to improve coordination and approval. The objective was to improve process efficiencies to increase target availability in support of mission objectives and strike operations.

According to Operation Allied Force collaborative session participants, the process used prior to applying collaboration is important to understand in order to fully appreciate the benefits gained by modifying the process to use collaboration. Nine geographically separated sites worked on and coordinated products sequentially. One site forwarded its initial work as email attachments, message traffic, fax, and/or phone calls to other sites with different responsibilities. Another site made product changes and sent the updates to participating sites. The process continued until the final product was sent to decision-makers for review and approval. Decision-makers received an email with the attached product information and either accepted the product information or returned it for further development.

The serial workflow extended the process timeline and provided opportunities for the nine sites to introduce ambiguities and errors. Participants indicated that communicating point-to-point, without consensus of other participants, created confusion, reduced accuracy of product information, and caused duplication of efforts. The sites involved did not always have a thorough understanding of other sites' tasks and goals. Therefore, some sites only understood the purpose, interdependencies, and value of their contributions from a parochial perspective. Process deficiencies made execution and approval too time consuming and difficult due to the following:

- Redundant information flowing to decision-makers
- Sequential coordination and approval by multiple organizations
- Maintaining currency of information and products existing in multiple versions and media types
- Understanding the rationale behind changes to avoid repetitious errors
- Tracking the status of products held for refinement or outstanding action
- Inconsistent quality control and standardization

Process and Participants: The collaborative sessions supported portions of the overall targeting process.

[5] Kosovo/Operation Allied Force After-Action Report to Congress, 31 January, 2000, p.24

[6] Kosovo/Operation Allied Force After-Action Report to Congress, 31 January, 2000, p.87

The USEUCOM targets community used sessions to construct and obtain theater agreement on final target approval briefings for decision-makers. The USEUCOM process owner is the Chief of Targets, Headquarters European Command Targets branch. Participants included:

- HeadQuarters United States European Command (HQ USEUCOM) Stuttgart, Germany: Targets, Crisis Action Plans, Judge Advocate/Operations Law
- Joint Task Force (JTF) NOBLE ANVIL Naples, Italy: Joint Target cell, Judge Advocate (JA)
- United States Air Force Europe (USAFE) Ramstein AB, Germany: 32nd Air Intelligence Squadron (AIS) Targets
- Joint Analysis Center (JAC) Royal Air Force (RAF) Molesworth, United Kingdom: JAC Targets
- COMSIXTHFLT Gaeta, Italy: TLAM Strike Cell, Plans and Targets
- Defense Intelligence Agency (DIA)/Joint Staff (JS) J2T Washington DC: Targets
- Combined Air Operations Center (CAOC) Vicenza, Italy: CAOC Targets US representatives

Approach: Daily, USEUCOM and US national-targeting agencies held regularly scheduled, collaborative sessions. A standardized template containing specific target information required for approval aided the communication and coordination process. The template standardized terminology and ensured accurate documentation of required targeting information prior to delivery to executive decision-makers. The collaborative sessions focused on targeting information. Participants used a concept of operations with roles and responsibilities and standard operating procedures to properly prepare for and control sessions.

The Joint Task Force (JTF) targets cell led the sessions. Headquarters USEUCOM targets branch controlled the target information during sessions and monitored quality control. Intelligence product development or other functional personnel (e.g., legal and operations) contributed to or reviewed the product information. Collaboration enabled participants to view imagery products and collate existing intelligence information into a single product. Collaboration allowed the target information to be reviewed, discussed, modified, and documented concurrence of JTF decisions and action items. The JTF targets cell approved or held target information for release to crisis action plans branch. The crisis action plans branch forwarded the target information to executive decision-makers for final approval or provided additional requirements during the session.

Results: The collaborative sessions successfully facilitated the coordination and approval of fixed targets during the Operation Allied Force air campaign. USEUCOM and US national target intelligence analysts used collaboration effectively to share intelligence information. Collaboration greatly aided the production of target materials used by senior level decision-makers (e.g., United States National Command Authority (NCA) and North Atlantic Council (NAC). USEUCOM targets community representatives estimate that the timeline decreased from 2-4 days to 2-3 hours. Participants indicated that coordination and synchronization benefited, improving process efficiencies and product quality. The collaborative sessions required detailed target development work prior to convening a session. This work is dependent on a sufficient number and right functional combination of trained personnel with access to current and accurate information. The USEUCOM targets community believes the potential exists to improve the quality and timeliness of intelligence throughout the targeting process by modifying processes to include collaboration where appropriate.

Collaboration removed or reduced the process deficiencies describe under *Need and Objective.*
Posting synchronized information to web-sites replaced multiple email attachments that contained product information and modifications. Simultaneous participation improved the feedback cycle. As a result, the rework time of target information for approval briefings significantly decreased while the overall understanding and ultimate value of the information significantly improved.

Another indication of success is the USEUCOM targets community continued use and refinement of collaborative sessions to support operations and contingency planning. Collaborative sessions are now applied from beginning-to-end for target development, nomination, and production processes. USEUCOM's dynamic Area of Responsibility (AOR) required expansion of participants since Operation Allied Force. As a result, eight new sites now participate in collaborative sessions.

Synchronization and Sharing of Current Intelligence

Need and Objective: The decentralized, independent, and point-to-point sequential phone coordination of USEUCOM intelligence watches often results in circular or unsynchronized reporting. The Director of Intelligence and HQ USEUCOM Watch Chief requested that the USEUCOM watches use collaboration to begin working together as a single watch.

Process and Participants: The USEUCOM Watch community's collaborative sessions are aimed at enhancing intra-theater intelligence watch coordination, synchronization, and situational awareness by facilitating a single, comprehensive intelligence picture among USEUCOM's geographically dispersed intelligence watches. The Watch community holds daily sessions, where each organization's important issues are presented and discussed. Ad-hoc meetings can be called to coordinate and share reports on high-interest or fast breaking events. Stations from other theaters or from the national community may participate. The goal is for collaboration to become the primary means of coordination among USEUCOM intelligence watches.

USEUCOM had to identify and appoint a process owner. The intelligence watches across USEUCOM did not have a theater-level process owner. The Intelligence Production Chief appointed the Chief of the Headquarters European Command Watch as the process owner. Participants include

- HQ EUCOM Stuttgart, Germany: HQ Watch, Crisis Action Team (CAT) Watch (when active)
- Joint Analysis Center (JAC) Royal Air Force (RAF) Molesworth, United Kingdom: I&W Watch
- United States Air Force Europe (USAFE) Intelligence Operations Center (IOC)

An expansion plan to add intelligence watches across USEUCOM is being executed.

Approach: The Director of Intelligence's daily top issues and priorities are the focus for sessions. A concept of operations and standard operating procedures are used to focus and control watch sessions. Headquarters USEUCOM Watch leads the session and shares the top intelligence issues with participating watches. Each participant watch obtains leadership's top intelligence issues and priorities, provides an update status on each issue, and recommends adding issues. Session results are documented and posted to a web-site. Addressing fast-breaking events, developing spot reports, and working issues together using collaboration to share and analyze intelligence data (e.g., maps, imagery, and reports) are planned.

Results: The watch collaborative sessions are held daily. USEUCOM is executing the plan to expand site participation and insert additional collaborative techniques and capabilities into sessions. For example, watch sessions may use whiteboard capabilities to share imagery, review and adjust indicator lists, and review maps and charts that have situation overlays. The daily sessions are institutionalizing a collaborative mindset and are providing a foundation for significant returns. The daily review and coordination of the top intelligence issues:

- Ensure awareness of the Director of Intelligence's top issues and priorities
- Provide components and Joint Task Forces (JTFs) the opportunity to modify or update daily issues
- Provide a forum to submit new issues
- Improve synchronization of current intelligence and operations
- Expedite situational awareness concerning developing events
- Allow non-participants to obtain session results from a web-site

Participant Comments on Applying Collaboration to USEUCOM's Mission Processes

As USEUCOM's experiences demonstrate, collaboration can mitigate the effects of information overload, improve team decision-making, and synchronize situational awareness. Colloboration provided one means to execute a theater-federated process with worldwide participants as described in the Report to Congress. "A federated intelligence process was instituted to facilitate burden-sharing among intelligence processing centers worldwide. This approach reduced deployment costs while maximizing the use of existing finite resources. The federation process was highly successful and depended on information sharing and agreements among participants. It would not have been possible, however, without applied technology, innovation, and pre-planning of exercises." [7]

According to Operation Allied Force participants, collaboration appears to be positively impacting the coordination, synchronization, accuracy, quality, and timelines of USEUCOM mission processes. USEUCOM experiences using collaboration demonstrated some of the phenomena anticipated by the Joint Vision 2010. " Joint Vision 2010 anticipates these phenomena — from use of technologies such as video teleconferencing — by observing '...higher echelons will use these technologies to reduce the friction of war and to apply precise centralized control when and where appropriate. Real time information *will likely drive parallel, not sequential planning and real time, not prearranged, decision-making.* The optimal balance between centralized and decentralized command and control will have to be carefully developed as systems are brought into the inventories'."[8]

Participants made the following comments on the benefits of collaboration to USEUCOM's mission processes. The comments are divided into four categories.

- Process Improvements
- Productivity Improvements
- Product Improvements
- Resource Alternatives

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[7] Kosovo/Operation Allied Force After-Action Report to Congress, 31 January, 2000, p.53

[8] Kosovo/Operation Allied Force After-Action Report to Congress, 31 January, 2000, p.28

Process Improvements

- Provided an easy method to keep participants informed on current process and product status
- Raised concerns and ensured participants knew process steps
- Brought various disciplines together and enabled cross-functional (e.g., intelligence, operations, legal) process participation
- Added quality to the product review process
- Facilitated the coordination process prior to product delivery to executive decision-makers
- Provided a regularly scheduled forum where thoughts and ideas could be traded based on knowledge, experience, and facts that each participant provided
- Brought time-sensitive products to the attention of the key players in the approval process. Reduced frequency of losing products in the approval queue where they could spend weeks before being worked.
- Eliminated serial workflow and reduced the number of product modifications. The difficult and convoluted process went smoother and faster after the collaborative sessions began.[9]
- Provided a forum for sites to make a final, coordinated check and provide late-breaking updates on product information

Productivity Improvements

- Provided an exponential increase in productivity
- Decreased estimated production time significantly
- Reduced the discussion and lead site's approval cycle of products
- Revolutionized the process, significantly reducing staff effort

Product Improvements

- Advanced the development of a standard template for presenting product information, creating a consistent product for decision-makers
- Provided a single product template that represented each product's information. This template provided participants with a common reference point that resulted in better understanding and improved team decision-making.
- Synopsized complex product information and gave participants a common frame of reference to facilitate discussion. Product templates were suitable for presentation to executive decision-makers, further streamlining the approval process.

[9] Participants realized that the serial decision process is not necessary given up-front, collaborative coordination. Once a primary decision is made, many subsequent actions do not require additional decisions to be made. The decisions only need to be executed.

Resource Alternatives

- Provided senior to mid-level decision-makers and operators (e.g., targeting and analytical) an alternative to video teleconferences (VTCs) that were dominated by flag-level officers
- Let operators participate from their workspaces and allowed access to key information and materials during sessions

Collaboration with NATO Allies

"Although experience in Operation Allied Force confirmed that the United States and our allies have made significant accomplishments working together, it also made clear that improvements are necessary... Among the most important of these are deficiencies in command-and-control and information systems, secure communications, precision strike capability, air operations support, and mobility systems. During Allied Force these shortcomings ... impeded our ability to operate more effectively with NATO allies."[10]

This section discusses the requirement, recommendation, and challenges associated with improving collaboration between NATO allies to support operations.

1. Operation Allied Force demonstrated that collaboration with NATO allies is necessary. Several USEUCOM military operators validated that collaboration with NATO allies is an operational requirement.
2. USEUCOM recommendations are provided for NATO's consideration in satisfying the requirement to improve collaboration between NATO allies
3. Challenges and issues faced by USEUCOM to apply collaboration successfully are described. NATO may encounter some similar and some unique challenges and issues.

Collaboration with NATO Is an Operational Requirement

Operation Allied Force clearly demonstrated, collaboration with NATO allies is necessary. One lesson learned by the USEUCOM targets community is that increased and improved collaboration between NATO allies to support the targeting process is needed. As a result, USEUCOM operators have stated the requirement to collaborate with NATO to support operations. Since USEUCOM is a participant in NATO operations, a reliable collaborative capability with NATO counterparts is essential.

Several USEUCOM operators stated that improved collaboration with NATO allies is a top priority.

[10] Kosovo/Operation Allied Force After-Action Report to Congress, 31 January, 2000, p.xix

Intelligence operations and geo-spatial information services personnel validated the requirement to collaborate with NATO allies. A US representative at the Combined Air Operations Center (CAOC) targeting cell stated the requirement to allow collaboration across security enclaves (SECRET US ONLY to SECRET RELEASABLE TO NATO). NATO should continue or begin to address the challenges and issues with increased emphasis and additional resources to improve or replace existing capabilities between NATO allies and satisfy the collaboration requirement.

Recommendations to Satisfy the Collaboration Requirement

Based on Operation Allied Force lessons learned, NATO should consider satisfying the collaboration requirement. First, NATO might consider satisfying this requirement within the targets community focusing on target development and nomination, target approval, and Air Tasking Order (ATO) generation and management.

Tasking an existing or new NATO working group to work the collaboration requirement is offered for NATO's consideration. The working group could:

- Coordinate with NATO and member nation operators to identify a process owner and develop a Concept of Operations
- Develop Standard Operating Procedures and provide training
- Work with NATO network domains and site technical representatives to develop an architecture that maximizes interoperability and integrates into the enterprise baseline and participant sites' system baselines
- Work with information security representatives to provide procedural and technical solutions that meet accreditation and security risk management requirements

Challenges and Issues to Satisfy the Collaboration Requirement

Like USEUCOM, NATO will encounter challenges and issues to satisfy the collaboration requirement. The working group will need to address the NATO and Member Nations' challenges and issues encountered. USEUCOM has encountered and addressed several challenges and issues that NATO may encounter. Some challenges and issues faced by NATO may be more complex than or different from USEUCOM's experiences since NATO is a supra-national organization comprised of multiple sovereign nation-states. Some of the challenges and issues that may need to be addressed are:

Policy: Leadership, representing both NATO and member nations, must identify what information and products can be shared during collaborative sessions. Otherwise, releaseability issues may reduce the benefit collaboration can have on time sensitive mission processes. Leadership must balance the risk associated with conducting NATO collaborative sessions against the potential consequences to personnel and mission if information is not shared in a timely fashion. Collaboration and information sharing is always a risk and requires investments of time, staff, and other resources. Leadership must determine whether the investment and risk of sharing information is worth the potential returns. A compromise between the "need to know" and "need to share" policies needs to be made.

For example, U.S. information releaseability policy may inhibit collaboration with NATO unless modifications are made. "In addition to dissemination problems on the data networks discussed above, U.S. sensitivity to releasing certain types of information greatly inhibited combined planning and operations in some areas."[11]

The Report to Congress addresses facilitating distribution of U.S. intelligence products to warfighters and allies. "Much of the U.S. information in question should be classified at the SECRET collateral level releasable to the coalition operation so that it can be effectively used by both U.S. and coalition warfighters. To the extent possible, imagery and signals intelligence data should classified 'SECRET/NOFORN Releasable to NATO,' and sources and methods should be protected 'by exception,' rather than the other way around."[12] "The Department will explore ways to permit intelligence and other information to be classified at the lowest possible classification level in order to ensure its availability to warfighters and coalition partners, while still protecting intelligence sources and methods."[13]

Process Owners and Concept of Operations (CONOPs): The identification and appointment of a process owner with existing or formally announced, delegated executive authority that is recognized by all participant sites may be more complex since NATO is a supra-national organization. Likewise, a dedicated, cooperative effort will be required to develop a useful CONOPs .

Infrastructure and Interoperability: The network connectivity and information infrastructure required for collaboration needs to be provided to participant sites. USEUCOM's collaborative efforts leveraged existing U.S. infrastructure and connectivity. General systems

[11] Kosovo/Operation Allied Force After-Action Report to Congress, 31 January, 2000, p.50

[12] Kosovo/Operation Allied Force After-Action Report to Congress, 31 January, 2000, p.51

[13] Kosovo/Operation Allied Force After-Action Report to Congress, 31 January, 2000, p.134

engineering expertise will be required to assist with the planning and management of the supra-enterprise architecture.

The Report to Congress highlights problem areas. "Although successful in some areas, NATO [command, control, communications, and computers] C4 capability was limited by the lack of C4 agreements and the need for more stringent enforcement and implementation of existing agreements. Problem areas included (1) sharing of bandwidth and C4 assets, (2) C4 network integration training standards at the combined and joint task force level, (3) spectrum management within combined and joint task forces, (4) network security, (5) lack of timely compliance with NATO standardization agreements (STANAGs), and (6) releasability of information. In addition, the C4 host nation agreement process needs to be expedited, and the focus of the agreements should be on standards and architectures rather than specific hardware."[14]

"Information interoperability was sometimes a major problem. This was true during both U.S. joint operations and combined NATO operations. Interoperability concerns were noted in how information is disseminated (the supporting C4 infrastructure) and how to disseminate it securely (releasability of various levels of classification). Dissemination networking and procedures were ad hoc, and it was never possible to present a common operational picture to joint and allied commanders... In summary, we see that interoperability will be the cornerstone for future alliance participation."[15]

NATO and U.S. are providing mechanisms to assist in formalizing command, control, communications and computers (C4). Formal C4 policies will likely benefit efforts to provide a collaborative infrastructure by addressing needs documented in the Report to Congress. "As the United States and NATO fielded these capabilities, some policy differences emerged that highlighted the need for increased emphasis and coordination in the alliance. The Defense Capabilities Initiative and NATO's Strategic Concept provide mechanisms to assist in formalizing C4 policies. Intensive efforts in this vital area of alliance command, control, communications, and computers will contribute to improved interoperability and reduction in the imbalance in capabilities."[16]

One possibility is to use NATO's existing network domains as a starting point. The four key NATO intelligence network domains should be considered in the analysis and development of solutions. The four key NATO intelligence network domains are:

- The NATO-nations Battlefield Information and Collection Exploitation Systems (BICES)
- Allied Command Europe's (ACE) ACE Command and Control Information System (ACCIS) centered around CRONUS, with its intelligence applications
- Allied Command Atlantic's (ACLANT) Maritime Command and Control Information System (MCCIS)/National Intelligence Data Transfer System (NIDTS), with its intelligence applications
- United States European Command's (USEUCOM) Linked Operations-Intelligence Centers Europe (LOCE)

Other NATO networks that are used by different functional communities should probably also be considered. Operation Allied Force demonstrated clearly the need and benefits of having the required combination of functional representatives (e.g., intelligence, operations, legal) participate in collaborative sessions.

The Intelligence Projects Integrated Working Group (IPIWG)[17] continues to discuss issues such as the use of collaboration tools. Web access and email capabilities are already available between NATO domains and partially satisfy the collaboration requirement. BICES is currently evaluating and attempting to use some collaborative capabilities. NATO could benefit from the International Military Staff (IMS) Intelligence Division and the IPIWG working together on collaboration. This group could build on the existing network domains to provide an initial set of collaborative capabilities.

Culture: Differences in culture, language, automation skills, as well as experience in collaboration and information sharing may impact mission groups in NATO more than USEUCOM. Symbology, terminology, and language usage need to be standardized.

Funding: The acquisition approach and resources to provide collaboration and the associated dependencies (e.g., infrastructure, operational and technical support, and training) must be determined.

[14] Kosovo/Operation Allied Force After-Action Report to Congress, 31 January, 2000, p.47, 48

[15] Kosovo/Operation Allied Force After-Action Report to Congress, 31 January, 2000, p.49, 51

[16] Kosovo/Operation Allied Force After-Action Report to Congress, 31 January, 2000, p.26

[17] SHAPE's ACE Intelligence Architecture Working Group (AIAWG) created the Intelligence Projects Integration Working Group (IPIWG) and tasked it to develop a feasible, Near-to-Mid Term NATO Wide Intelligence Architecture taking into account existing systems and ongoing projects. The four major NATO intelligence-related systems (or domains) listed above are part of this effort.

Lessons Learned and Best Practices from USEUCOM's Collaborative Experiences

USEUCOM experienced several overarching lessons learned and improvements needed that are documented in the Report to Congress. "...[T]he Department needs to further develop and refine tactics, techniques, and procedures for federated intelligence efforts and to reassess and size long-haul communications needs accordingly. Planning for intelligence communications needs must include deployable systems and technicians. Additionally, the Department needs a clear policy and implementation plan to explain when and how coalition partners can be connected to U.S. networks and, when and how data can be shared with those partners."[18]

"The widespread use of video teleconferencing and other advanced technologies for command and control and collaborative planning presented numerous limitations and challenges. In order to optimize the application of these systems and accustom operational commanders to their effects, appropriate doctrine, tactics, techniques, and procedures must be developed. In addition, these technologies should be included regularly in future large-scale joint and combined training exercises."[19] USEUCOM's lessons learned and best practices using collaboration may assist in optimizing the application of collaboration and accustomizing operational commanders to the effects of collaboration.

Lessons learned and best practices from USEUCOM's experiences are provided for NATO's consideration and potential use to satisfy the collaboration requirement. Lessons learned and best practices are grouped into three categories.

- Technical
- Operational
- Accreditation and Approval to Operate

Technical Lesson Learned and Best Practices

According to Operation Allied Force participants, the performance, reliability, and simplicity of the collaborative capabilities within the operational environment are the primary factors that affect operator acceptance and use. The technical lessons learned and best practices that assisted in providing collaboration capabilities with acceptable performance, reliability, and simplicity in the USEUCOM operational environment are provided below.

Basic Capabilities: Capabilities need to be simple to allow operators with basic computer skills to participate. A trade off between complex capabilities and keeping the system simple should be made with military operators. Use of capabilities will probably evolve as the process matures and increased benefits are realized.

Network Infrastructure and Architecture: Collaboration is dependent on network infrastructure and connectivity to mission-essential participants. The stability, network capacity (bandwidth), and configuration of the network infrastructure directly impact the performance and reliability of collaborative sessions. Network capacity should be viewed as an operational resource. Operators should perform a cost-benefit analysis that compares the mission benefits of collaborative capabilities with other capabilities and requirements that consume bandwidth. An optimal mixture of network infrastructure, design of the collaborative capabilities, and procedural techniques are required to maximize performance and reliability.

The impact to network bandwidth needs to be assessed. Accreditation and the "approval to operate" are based on this assessment. Network impact is difficult to assess since items that consume bandwidth change dynamically during a collaborative session. It is similar to asking what is the impact to network bandwidth of email with attachments or Internet activity.

Some variables that affect performance, reliability and required network bandwidth are:

- Enterprise server location based on an analyses of several items listed below
- Physical location of participants
- Number of simultaneous participants from Local Area Network LAN, from Wide Area Network (WAN)
- Concept of operations (e.g., roles and responsibilities)
- Frequency of server access and file transfers across LAN and WAN
- Information structure and movement within the process
- Technical support
- Collaborative techniques and procedures used (e.g., single-point application sharing vs. giving control to multiple different sites, sharing multiple small files or one large file)
- Collaborative capabilities used
- Size of information being shared
- Configuration of enterprise servers and workstation clients (e.g., audio codec selected)
- Network architecture, management control, and distribution path alternatives

The mission process using collaboration should be compared with the old process as a way to view and assess the overall impact to network capacity. For

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[18] Kosovo/Operation Allied Force After-Action Report to Congress, 31 January, 2000, p.53

[19] Kosovo/Operation Allied Force After-Action Report to Congress, 31 January, 2000, p. xxii

example, the modified process using collaboration eliminated numerous emails with attachments sent by multiple sites to multiple sites during the old process. This network capacity savings should be included in the overall assessment.

Integration: Integration of collaborative capabilities into the enterprise baseline and into each participant site's local system baseline is recommended. Capabilities should require few modifications to existing baselines. Requiring a separate workstation for collaboration in existing spaces is not acceptable. The collaborative capabilities should work on existing workstations with minimal modifications. Collaborative capabilities should be independent of workstation make and operating system. Workstation make and operating system independence decreases investment costs and increases the probability of new participants quickly joining the collaborative architecture at garrison and deployed sites.

The collaborative capabilities (e.g., text chat, voice audio), mission applications (e.g., presentation and imagery software), site information repository (e.g., local or network drives where information is stored), and software product templates were integrated into the existing enterprise or sites' system software baselines. Collaborative capabilities must be developed to work within the designated environment's system baseline configuration. The collaborative capabilities must interoperate with the network infrastructure, software (e.g., browser profiles, security permissions, and user account privileges) and hardware (e.g. sound cards) baselines. Collaborative capabilities with a high degree of integration into or interfaces with the enterprise or sites' system baselines should be resilient as possible to baseline component configuration settings and system baseline changes.

Collaborative session participants continue to access their local site's information repository, from workstation or site network drives. No additional effort is required to retrieve, store, and post or disseminate information. Participants use the site information repository since the familiar structure allows information to be located efficiently. Participants develop and share products by using local mission applications software. Integration significantly reduces application and information repository training requirements.

Acceptance Testing: Testing the collaborative capabilities' performance and reliability in the operational environment prior to acceptance is imperative. Collaborative capabilities may meet a specification and perform well in a laboratory environment. However, the system may not integrate easily or well into the operational enterprise baseline and participating sites' baselines.

Interoperability: Collaborative capabilities should be interoperable with enterprise and participating sites' mission application software. Proprietary software or equipment should be avoided. Adhering to commercial international standards increases the probability of achieving interoperability. Using mainstream commercial products improves the ability to evolve with future technologies while providing operators capabilities today.

Configuration Management: Configuration management and testing need to be approached from a mission group perspective. The mission group perspective consists of interdependent baselines. Configuration management and testing of interdependent baselines present unique challenges compared with traditional independent baselines. Interfaces and dependencies of the interdependent baseline must be identified and tested when collaboration dependent participant sites' or enterprise baseline configuration items are modified. For example, one participant site may upgrade the browser component of its baseline. The browser upgrade may make some collaborative capabilities (e.g., audio, and text chat) incompatible with the existing enterprise capability used by the mission process group. Therefore, the site's baseline must be made compatible with the mission process group's capabilities.

Technical Support: Technical support is required on a 7 day by 24-hour basis during operations. Technical support representatives need to assist operators and team with local technical personnel. Local technical personnel are often required to isolate and resolve technical issues manifested as symptoms when using enterprise collaborative capabilities. The symptoms could be caused by the local site's system baseline or network infrastructure and only experienced when using collaborative capabilities.

Professional Relationships: Integration of collaborative capabilities into the enterprise and sites' baselines to achieve good performance and reliability depends on professional relationships developed between general systems engineering and site technical and security personnel; and between general systems engineering representatives and military operators. Good professional relationships between participating sites' military operators, technical and security personnel are instrumental in successfully achieving the implementation of the collaborative capabilities.

Operational Lesson Learned and Best Practices

Technical lessons learned and best practices are not sufficient to realize the potential benefits of collaboration. Operational lessons learned and best practices must complement the technical ones. Operation Allied Force lessons learned demonstrate that collaboration can benefit mission effectiveness when judiciously applied to existing or modified processes, a process owner is appointed who carries out the recommended responsibilities listed below, and a Concept of Operations (CONOPs) is documented. Collaboration does not replace the need for the right functional combination of well-trained, prepared personnel who have access to current and accurate information. Operational lessons learned and best practices that contributed to using collaboration successfully during Operation Allied Force are provided below.

Appointment of Process Owner: The command or enterprise must identify and appoint a process owner with existing or formally announced, delegated authority and responsibility that is recognized by all participant sites. A process owner must be appointed for each collaborative mission group, mission process, or routine collaborative session, as appropriate. The process owner may appoint an operational advisor to assist with these responsibilities. Recommended process owner responsibilities are:

- Must understand the entire process and the current operation in detail
- Own and provide mission group's requirements
- Identify participants and sites
- Coordinate with and assist participant sites to get capabilities funded and implemented
- Provide military direction, guidance, and information to participants
- Develop Concept of Operations (CONOPs) (e.g., how to use when and where to meet; define and assign roles and responsibilities before, during, and after session.)
    - ➢ Identify what sites will have the leader, information coordinator, and/or production developer role(s).
- Provide network connectivity requirements
- Identify process and products, for potential modification with collaboration
- Develops the Standard Operation Procedures (SOPs). The SOPs document session step-by-step specific instructions for each participant. The SOP development is instrumental in modifying the process, selecting and developing collaborative techniques, capabilities, and standardized product templates.

Concept of Operations (CONOPs): Defining roles and responsibilities and preparing for the collaborative sessions is important to achieve success. The process owner or delegate leads this effort with the assistance of the general systems engineer. Session roles (e.g., leader, information coordinator, product developer) and responsibilities assigned take into account the process timeline, experience, control desired, command structure, and number of participating sites. Participants have the capability and opportunity to provide local expertise. The interdependent roles and responsibilities require definition for the "before", "during", and "after" phases of the collaborative session. These roles and responsibilities are critical to establish and execute successful sessions. Roles and responsibilities of federated partners must also be defined and documented. All sites, except site(s) with the lead role, participate for coordination purposes. Examples of three key roles[20] are listed below.

Leader: The leader works with the information coordinator to ensure preparation and execution of collaborative sessions.

Before Session

- Determine what items to review and assign preparation responsibilities
- Identify products to review and revisit during session
- Inform sites of key personnel and functional skill mix required during session
- Develop agenda and set schedule

During Session

- Focus on running the session and obtaining results in a reasonable time frame
- Task development work and issue priorities
- Assign action items and suspenses
- Chair session in close coordination with information coordinator
- Approve or hold information and product release
- Act as final authority on questions and decisions

After Session

- Write and provide summary of session and actions to participants

Information Coordinator: The information coordinator works with the leader to ensure preparation and execution of collaborative sessions. The information coordinator is responsible for information and product management.

Before Session

- Schedule session time and setup conference on server
- Coordinate agenda with session lead site
- Test participant sites' systems
- Gather product information for sessions

During Session

- Manipulate data and share product information with participant sites
- Make and save final product changes
- Record text log of significant audio discussion, decisions with rationale, actions, suspenses, and product hold or approval status

After Session

- Save log and provide to participants
- Post products in proper format for participants, consumers, and next phase of process

Product Developer: The product developer provides

[20] A site may have multiple roles or role may be shared by multiple sites.

product information to the information coordinator before or during sessions.

Before Session

- Perform detailed development, research, and analysis
- Address data and information shortfalls
- Develop product for session review

During Session

- Obtain priorities from lead
- Provide rationale or explain product information

After Session

- Work action items assigned from lead site

Product and Information Management: The information coordinator works with the process owner or delegate and the general systems engineers on the following tasks.

- Select mission application software to use and develop standard product templates to organize information that is the focus of the collaborative session
- Determine information used in session, information structure, and information repository location for products
- Determine product format
- Develop an information flow and structure to transfer and hold product information between various stages in the process
- Develop information change procedures to ensure the currency, accuracy, and integrity of the information. Information change procedures for shared information is critical to provide version control and conduct successful collaborative sessions.

The importance of information management to conduct productive collaborative sessions cannot be over emphasized.

Nurturing: Nurturing is an important human factor component to successfully apply collaboration. Nurturers assist in institutionalizing collaboration as an alternative method for supporting mission processes and inserting additional collaborative techniques and capabilities as military operators' work schedules permit. As a minimum, a nurturing team should have a general systems engineer and military operator to bridge across each other's disciplines. The resources and time spent with operators on modifying mission processes and applying technology should be equal to or greater than resources and time spent on technology development and fielding issues to improve overall mission benefit. "Buttonology" training is not sufficient. Mission process training proved to be beneficial in executing collaborative sessions with mission groups.

Personnel, Data, and Preparation: Successful collaborative sessions are not guaranteed. Conducting successful collaborative sessions is similar to holding productive meetings. The existence of current, accurate, and validated information is important. The right functional combination of trained personnel to prepare for, participate in, and contribute to collaborative sessions are paramount to conducting successful sessions, making good decisions, and ensuring product quality.

Session Participation Control: Mission process owners control collaborative session participation. Process owners or designates must be able to immediately add or delete participants to sessions. Participants required network access accounts on a properly configured workstation. This is important since operators may deploy to various sites and numerous augmentees assist locally or in a federated manner during crises. Battle rhythm and mission requirements often dictate expedient addition or deletion of participants. Participants require group or organizational accounts to improve collaboration benefits to some mission processes.

Some reviewers indicated that using collaboration in a NATO environment may be less open than U.S. only sessions. Controls on participation, including the country level, need to be provided with the appropriate privacy and security mechanisms to allow flexible selectivity to address releaseability issues during collaborative activities.

Accreditation and Approval to Operate Lessons Learned and Best Practices

Obtaining accreditation and "approval to operate" for collaboration requires dedicated effort. Personnel who provide accreditation and give "approval to operate" for information systems must be included in the team from the beginning. Sharing information and collaborating over networks requires close cooperation with information security representatives to implement procedural and technical solutions that satisfy both collaboration and accreditation requirements.

Summary

The United States European Command (USEUCOM) is applying collaboration successfully in an operational environment to support deliberate and crisis planning, and operations. According to Operation Allied Force operators, proper application of collaboration improves the effectiveness of information processes, improves product quality, and benefits federated efforts by geographically separated partners. Collaboration allows USEUCOM's geographically separated sites to work as a team and manage increased battle management complexity by mitigating the effects of information overload, improving team decision-making, and synchronizing situational awareness.

USEUCOM's Operation Allied Force lessons learned clearly show the requirement to work with NATO allies in a collaborative environment. USEUCOM operators validated the requirement to collaborate with NATO allies. USEUCOM senior leadership and the targeting community are leading advocates for this requirement. NATO should consider satisfying the collaboration requirement. An existing or new working group could be appointed to energize, resource, and satisfy this requirement. First, NATO might consider satisfying this requirement within the targeting community, focusing on target development and nomination, target approval, and Air Tasking Order (ATO) generation and management.

USEUCOM encountered and addressed several challenges and issues to provide collaborative capabilities and apply collaboration to benefit mission processes. USEUCOM Operation Allied Force lessons learned and best practices are provided for NATO's consideration and potential use to satisfy the collaboration requirement. Technical lessons learned and best practices highlight performance, reliability, and simplicity as the primary factors that affect operator acceptance and use. Operational lessons learned and best practices demonstrate that collaboration can benefit mission effectiveness when judiciously applied to existing or modified processes, a process owner is appointed who carries out the responsibilities recommended, and a Concept of Operations (CONOPs) is documented. Collaboration does not replace the need for the right functional combination of well-trained, prepared personnel who have access to current and accurate information.

The investments made and risks taken by NATO and member nations to improve and increase collaboration could provide significant benefit to NATO's mission effectiveness and alliance solidarity by:

- Allowing military resources to be allocated more effectively and used more efficiently
- Improving alliance coordination, synchronization of situational awareness, and decision-making.

The "need to know" constraint must be balanced against the "need to share" necessity to satisfy time dependent allied operational requirements to execute effective missions.

Attachment 1

Primary Collaborative Techniques and Capabilities Used at USEUCOM

Text chat: Participants use text chat as one of the primary communication capabilities during collaborative sessions. A date/time-stamped, formal log is created and saved using text chat. Some users indicated that text chat is used more than audio once experience is gained using the system. Each product has a historical log with key points, questions, actions, and current product status. The information coordinator uses text chat to document key points and final decisions made using audio. The historical log allows participants to agree and view the group's final decision. Text chat allows sites to provide feedback to the information coordinator. For example, sites notify the session information coordinator when product information is in view. Text chat also provides an alternative means to communicate if audio is not available or practical.

Voice Audio: Participants frequently use the voice audio capability in a coordinated manner to express concerns that were not easily communicated with the text chat tool or to discuss contentious and complex issues. Normal military radio procedures ensure clarity and brevity. Audio is disabled when participants are not speaking to conserve bandwidth and reduce feedback. Audio significantly reduces the time to reach consensus or make decisions during sessions. Audio generates interaction and synergy, enhancing the quality of products. Overall, participants indicate text chat-only sessions slow and reduce the information exchange among key participants. However, productive sessions have been conducted using text chat only. Audio better enables the leader to direct sessions. The leader uses audio to guide the session while participants provide responses using text chat. Participants use audio to direct requests to the information coordinator for information or product manipulation. Operators emphasize that the combination of text chat and audio used in the right proportion is extremely beneficial and that both capabilities are required.

Application Sharing Capability to Share Products and Information: Application sharing provides products and information to participants during collaborative sessions. Single-point controlled application sharing is when a single collaborative session participant, the information coordinator, shares a digitized product or relevant information with participants. The information coordinator manipulates the application and modifies the product after the proposed changes are discussed via text chat and/or audio, and approved by the leader. The information coordinator does not give up control of the application. Reasons for using single-point controlled application sharing are to:

- Conserve bandwidth and reduce latency effects
- Allow control of session and reduce chaos
- Allow participation of new operators on different shifts from multiple sites with varying computer skills
- Keep techniques simple
- Reduce training requirements

Operation Allied Force military operators who participated in collaborative sessions commented on some of the benefits of application sharing. Application sharing:

- Maintains standard or native product file format and eliminates the need to perform format translation (e.g., From PowerPoint format to whiteboard format and back to PowerPoint format after collaborative session). Inflexible operational process timelines do not allow personnel to pre and post-process information. Operators prefer to work in the process product's native format, make changes, and save to the designated information repository.
- Allows use of core mission application software and provides the ability to take advantage of all the capabilities (e.g., zoom) resident in the application being shared
- Allows use of the primary information repository
- Allows participants to see the information coordinator's cursor movement. This is beneficial in providing feedback. Participants know that the information coordinator is manipulating the application. Using the whiteboard does not provide this feedback.

Whiteboard

Some sessions import imagery into the whiteboard to facilitate discussions. Participants share and annotate images using whiteboard capabilities to coordinate tasking and synchronize understanding. More team discipline and training is required when using whiteboard capabilities compared with single-point application sharing since any participant may modify the whiteboard at any time. The changes made during the session have to be repeated in the native application if the whiteboard does not support saving in the product's native application format.

Web-Based Technology

Web-based access to product information is a key component of USEUCOM's application of collaboration to mission processes. Providing information on web-sites significantly reduces staff workload by decreasing the number of duplicate email or phone requests for information. Rapid access to the most current and accurate information for intelligence and operations planning and execution provides a significant benefit according to Operation Allied Force participants. Web-based forms and databases reduce workload, limit ambiguities, and decrease the number of information updates.

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Aerial warfare	Culture (social sciences)	Knowledge management
Mission effectiveness	Design	Teams (personnel)
Situational awareness	Experimentation	

14. Abstract

On 10-13 April 2000, NATO, Partnership for Peace, and Non-NATO nationals from 21 countries met in Oslo, Norway to discuss the perceptual, cognitive, social, and contextual factors and considerations that will impact the usefulness and usability of information and information technologies in battle management operations. Sponsored by the Human Factors and Medicine Panel of the North Atlantic Treaty Organization's Research and Technology Organization, the symposium participants discussed the problem, research approaches and techniques for improving team performance and enhancing effectiveness, concepts for battlespace visualization and decision support, and the integration of collaborative battle management systems. The symposium included four Keynote Addresses and sessions on:

- Operational Problems in Battlespace Management;
- Team Performance;
- Techniques for Enhancing Battlespace;
- Visualization and Decision Support;
- Decision Support Considerations;
- Integration and Test of Battle Management Systems.

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