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NORTH ATLANTIC TREATY ORGANISATION

RESEARCH AND TECHNOLOGY ORGANISATION
BP 25, 7 RUE ANCELLE, F-92201 NEUILLY-SUR-SEINE CEDEX, FRANCE

RTO-EN-019

RTO LECTURE SERIES 227

Tactical Decision Aids and Situational Awareness

(Les aides à la prise de décisions tactiques et la connaissance de la situation des forces)

The material in this publication was assembled to support a Lecture Series under the sponsorship of the Systems Concepts and Integration Panel (SCI) and the Consultant and Exchange Programme of RTA presented on 1-2 November 2001 in Amsterdam, The Netherlands, 8-9 November 2001, Sofia, Bulgaria, 12-13 November 2001 in Madrid, Spain and 19-20 November 2001, Maryland, United States.

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The Research and Technology Organisation (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 the following 7 bodies:

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

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They 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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Tactical Decision Aids and Situational Awareness

(RTO EN-019 / SCI-113)

Executive Summary

This Report documents the results of NATO Research and Technology Organization (RTO) SCI-113 Lecture Series number LS 227, entitled “Tactical Decision Aids and Situational Awareness”.

This Lecture Series has been sponsored by the Systems Concepts and Integration (SCI) Panel and the material contained in this publication was presented on 1-2 November, 2001 in Amsterdam, The Netherlands, on 8-9 November, 2001 in Sofia, Bulgaria, on 12-13 November, 2001 in Madrid, Spain and on 19-20 November, 2001 at the Patuxent River Naval Air Station, Maryland, USA.

The primary purpose of this Lecture Series was to focus the LS audience on the current scientific and technical knowledge within the domain of Decision Aids Systems in relation to certain ongoing development programs.

The authors of the Lecture Series covered in particular the major problems to be addressed in the requirements definition, the state-of-the-art, the emerging technologies, the achievements, the expected benefits to the end-users, the lessons learned and the future trends.

Due to the fact that in the complex and fast-paced Battlespace of the future, humans will rely more and more on Information Technology to deliver knowledge and to assist them in using that knowledge, the *decisions* will be reached by a mix of human and machine reasoning.

The aim of the Decision Aids Systems is to achieve the *decide* and *act* capability.

The key enabling technologies to provide such a capability, as described in the Lecture Series, can be found in the area of the Information Technology and in the automation process of the man-machine integration, together with the accurate modelling of the human cognitive processes.

Special emphasis was given during the Lecture Series to the description of programs covering:

- Interaction of human perception and judgement with automated information processing and presentation
- Mission Management and Crew Assistance for Military Aircraft
- Pilot oriented workload evaluation and redistribution
- Interacting Multiple Model Approach in Dynamic Situation

The material in this publication was assembled to support a Lecture Series under the sponsorship of the Systems Concepts and Integration (SCI) Panel and the Consultant and Exchange Programme of RTO presented on 1-2 November 2001 in Amsterdam, The Netherlands, on 8-9 November 2001 in Sofia, Bulgaria, on 12-13 November 2001 in Madrid, Spain and on 19-20 November 2001 in Maryland, USA.

Les aides à la prise de décisions tactiques et la connaissance de la situation des forces

(RTO EN-019 / SCI-113)

Synthèse

Ce rapport présente les résultats du Cycle de conférences LS 227 sur “Les aides à la prise de décisions tactiques et la connaissance de la situation des forces” organisé par la Commission sur les concepts et l’intégration de systèmes (SCI-113) de l’Organisation pour la recherche et la technologie de l’OTAN (RTO).

Dans le cadre de cette activité, les textes contenus dans cette publication ont été présentés du 1 au 2 novembre 2001 à Amsterdam, Pays-Bas, du 8 au 9 novembre 2001 à Sofia, Bulgarie, du 12 au 13 novembre 2001 à Madrid en Espagne et du 19 au 20 novembre 2001 à la base aéronavale de Patuxent River, Maryland aux Etats-Unis.

Ce cycle de conférences a eu pour objectif principal de présenter l’état actuel des connaissances scientifiques et techniques dans le domaine des systèmes d’aides à la prise de décisions, tel que reflété par un certain nombre de programmes de développement actuels.

Les conférenciers ont notamment développé les principaux problèmes à aborder dans le cadre de la définition des spécifications, l’état actuel des connaissances, les technologies naissantes, les réalisations, les bénéfices escomptés pour l’utilisateur final, les enseignements tirés et les tendances futures.

Etant donné que les acteurs du champ de bataille complexe et dynamique du futur feront appel de plus en plus à des technologies de l’information pour transmettre les connaissances et pour être aidé dans leur exploitation, les décisions seront prises par le biais d’un processus décisionnel homme-machine.

Le but des systèmes d’aide à la prise de décisions est de parvenir à une capacité du type “décider et agir”.

Comme il est exposé dans le cycle de conférences, les technologies clés permettant de fournir une telle capacité se trouvent dans le domaine des technologies de l’information, dans le processus d’automatisation de l’intégration homme-machine ainsi que dans la modélisation précise des processus cognitifs humains.

Une attention particulière a été portée à la description de programmes couvrant :

- L’interaction entre le jugement et la perception de l’homme et la présentation et le traitement de l’information automatisée.
- La gestion de la mission et l’aide aux équipages des aéronefs militaires.
- L’évaluation et la redistribution de la charge de travail des pilotes.
- L’approche du modèle interactif multiple en situation dynamique.

Cette publication a été rédigée pour servir de support de cours pour le cycle de conférences organisé par la commission sur les concepts et l’intégration de systèmes (SCI)) du 1 au 2 novembre 2001 à Amsterdam aux Pays Bas, du 8 au 9 novembre 2001 à Sofia en Bulgarie, du 12 au 13 novembre 2001 à Madrid en Espagne et du 19-20 novembre 2001 à Patuxent River aux Etats-Unis.

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Introduction – Technical Overview and State of the Art

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Objective

Today the use of Decision Aids Systems for Commander and Operators in the Battlefield area is playing an important role due to the new frequent situation of joint coalition and asymmetic warfare in which Defense Forces are involved.
On these occasions, the capability of own Forces to follow the evolution of the Tactical Situation in real time is extremely important.
Since Combat Survival and Mission Accomplishment depend upon Operators performance in the process of decision-making, and the Operators performance depends upon the degree of awareness, Situation Awareness can be seen as a result of a continuous assessment of situation parameters by the Operators.
This Mission critical chain of sub-segment functions is greatly influenced by the nature of the technical systems the Operator is having to deal with.

The purpose of the present Lecture Series is to provide to the audience:

- Definition of the problem
- Overview of the state-of-the-art
- Description of some research and development programs
- Exposure to the end-users of the potential benefits of the decision aids employment
- Future trends

What is Decision?

Decision, following the Webster's Dictionary, means *"the act or process of deciding"*, and *to decide* means *"to arrive at a solution that ends uncertainty"*, as well as *"to make a choice"*.
This definition is correct for our purpose.

What is a Decision Aid?

In today's information-intensive Battlefield, Operators need decision aids to free them from information overload.

Decision aiding technologies fuse data from onboard sensors and outside sources to:

- Create a composite picture of the battlefield
- Recognize potential threats
- Impart key information to friend forces.
- Instantaneously update mission plans.

Paper presented at the RTO SCI Lecture Series on "Tactical Decision Aids and Situational Awareness", held in Amsterdam, The Netherlands, 1-2 November 2001; Sofia, Bulgaria, 8-9 November 2001; Madrid, Spain, 12-13 November 2001; Maryland, United States, 19-20 November 2001, and published in RTO-EN-019.

Key Elements of Decision-Aiding Software are typically:

- Data fusion - combines track information from a variety of sources into a single best picture of the Battlefield
- Situation assessment – continually monitors this dynamic picture for impacts to the plan
- Mission planners – recommend updates to the plan
- Execution aids - help the crew in executing the mission.

What is Tactical Decision Making?

In line with the above definition, *tactical decision-making* is the main task and responsibility of the *tactical decision-maker*, who is active at any level of the *tactical decision-making process*.
Unfortunely, the *decision* has to be based upon *tactical military information* and *operational environment* which are, by definition, always uncertain to varying degrees.
Therefore effective *tactical decision-making* refers primarely to the ability to use logical and sound *judgement* to make decisions on *available information*.
The *available information* is developing from the elementary external data collected by sensor systems to the *situational awareness* through a judgement process.
What above need to be supported by appropriate *decision aids* in order to improve operator performance.
The automation of the process has to be coherent with the above.

What is Situational Awareness?

Situational awareness is generally defined as the degree of accuracy by which the Operator's *perception* of the external environment reflects the *reality*.
To our purpose, *situational awareness* is instead to be defined as *"the ability to reliably, accurately and continuously collect information on the situation, enemy or friendly, when and where required"*.
In simple words, in the military environment *"it is the mechanism which pinpoints targets and threats to represent the Battlespace situation"*.
It is always to be reminded that, in line with the basic definition, *awareness* is a matter of degree and *not* an absolute.

Situation Awareness

Situation awareness is the major element of the *information superiority* which is needed for the *Battlespace dominance* by the *Systems of Systems*, in accordance with the updated Defense requirements.

Information Superiority

Information superiority is the result of the capability to gather, process, integrate, disseminate and display situation awareness information, together with a corresponding increase in the ability to use that information.
This ability is the *knowledge of the Battlespace*, which is necessary to *make decisions* and *take actions* allowing to dominate the *Battlespace*.
A very careful attention has to be put in obtaining the *knowledge*, so that it is coherent with the *cognitive processes*.

Only if this is reached, the *decision-making* is optimized and the man-machine loop is closed according to the requirements.

Automation aspects

Automation is a fundamental issue to achieve an improved operational effectiveness of the *decision-making* process.
This is due to the large amounts of data to be handled in dynamic and heavy scenario, which could overwelm Operators capabilities.
The fundamental problem encountered during the implementation of an effective automation is how support is provided by decision aid on elements of the decision-making.
The dualism is to use the decision aid as a *prosthesis* adding additional capabilities to the Operators or simply as a *tool* available to the Operators; the differences are related to the role of the aid in the decision process.
The *prosthetic approach* is targeted to replace the Operators when the situation causes an excessive workload that cannot be managed by the human capabilities and to provide the needed decision outcomes.
The *tool approach* is targeted to assist the Operators active role in accordance with the decision-making process requirements.
These approaches are not mutually exclusive but complementary, depending on situation context, the specific nature of the decision aid element and the Operators role.
The correct choice is let to the designers capability and experience.

Lecture Series Overview

The present Lecture Series concentrates on the discussion of examples of applications covering in particular:

- Interaction of human perception and judgement with automated information processing and presentation
- Mission Management and Crew assistance
- Approach to cognitive and cooperative Operators assistance in the field of Tactical Flight Mission Management
- On-board decision support techniques
- Pilot oriented workload evaluation and redistribution
- Multiple hypotheses multiple model approach techniques

The goal is that the detailed presentations together with the discussions of achievements, problems and lessons learned from the Programs shall help Decision Aids Systems potential designers and users in defining and evaluating operational requirements and affordable solutions.

An extensive use of the modern design and development processes and techniques based on the Systems Engineering, Systems Analysis, Functional Analysis, Simulation and Rapid Prototyping have to be considered for the success of the Programs.

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Tactical Decision Making: The Interaction of Human Perception and Judgment with Automated Information Processing and Presentation

I. Situational Awareness and Understanding

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Tactical decisions are made under conditions best described as "the fog and friction of war". They tend to be judgmental rather than analytical and are based on the decision maker's perception of the situation and of his or her options for meeting objectives defined by the commander. The perception and the resulting decisions are very sensitive to the quality and completeness of the knowledge that the decision maker obtains through interactions with the decision support systems.

Modern information technology provides enormous potential for expanded situational awareness using a variety of information management, display, and human-system interaction tools that can help the decision makers penetrate the "fog of war" and deal with the "friction of war". On the other hand, the increased use of automation also tends to remove the decision makers from direct observation of the situation and requires them to rely on information that is derived or inferred by processes that are embedded within a complex system of systems. This can impede the judgmental decision process due to lack of confidence in the information or due to a desire to obtain more information before committing to a course of action. The relationship between the human judgmental processes and the automated decision support systems is particularly important for tactical combat direction and execution, where the pressure to decide and act is intense and where the results of decisions are often lethal.

This lecture explores the process in which the decision maker achieves an awareness and understanding of the situation based on observations and on his or her model* of the world and of the current operational context.

*A model of the world is simply a set of rules and relationships that describe how entities and events occur and move through time and space. For example, our world model tells us that entities that move through the air are either birds or aircraft and that automobiles do not move through the air. A model of the context is a similar set of rules and relationships that describe how the elements of the world model are related to the current operational situation. For example, if our context is open ocean operations, our context model tells us that entities moving along the surface of the earth are most likely ships and not trains or automobiles. Similarly, if the context is peace, then our context model tells us that incoming aircraft are not likely to be attacking us.

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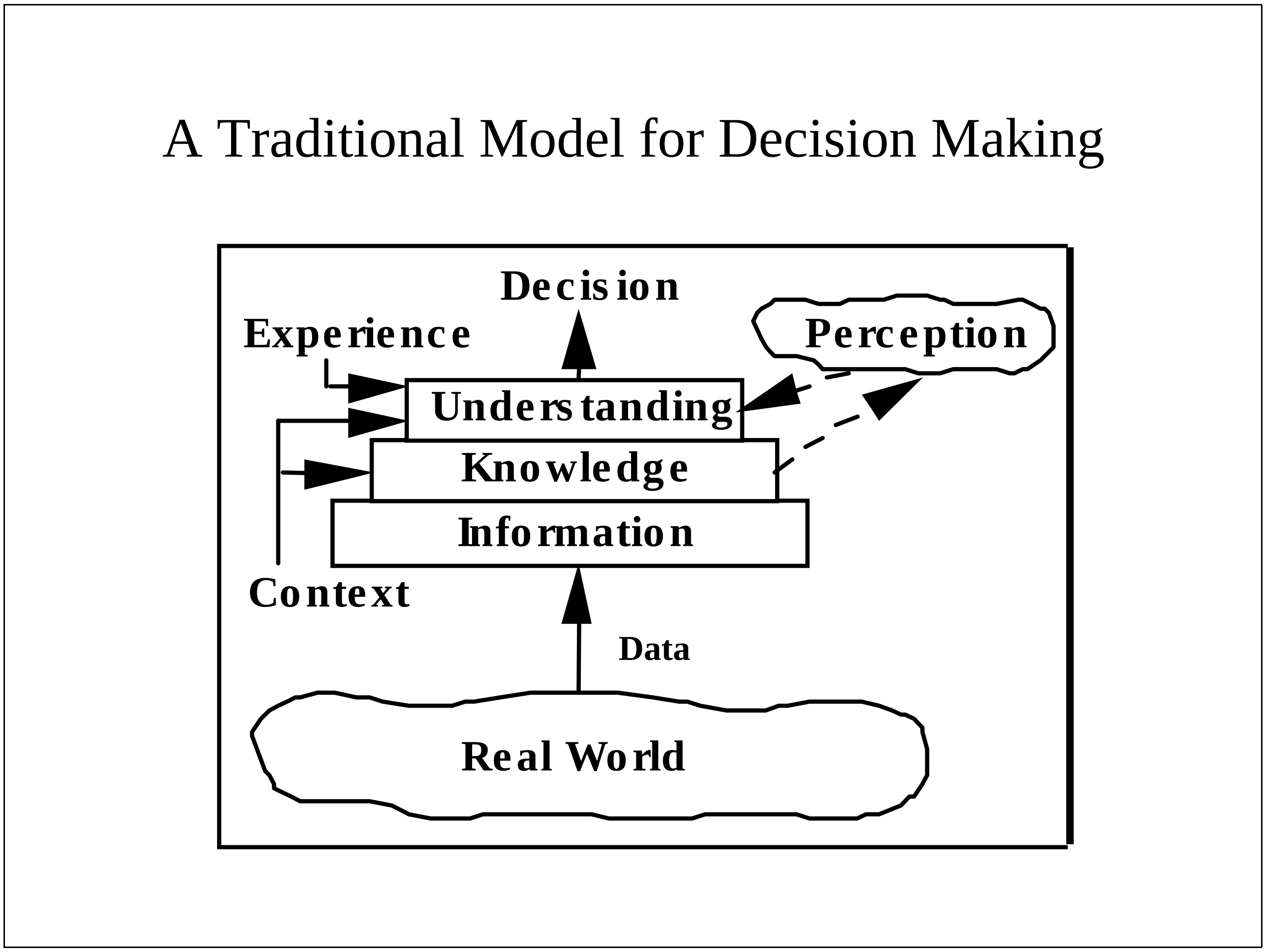

Figure 1. A Traditional Model for Decision Making

This is the first part of a two-part lecture dealing with situational awareness and tactical decision aids and the role of information technology in supporting the operational processes.

Figure 1 above shows a traditional model for moving from observed data to a perception of the situation and then to a decision on how to respond. This first lecture examines the cognitive process that leads to perception and understanding of the situation and the way that technology is used to support that process. The second lecture examines the further processes for reaching a decision to act upon that understanding of the situation.

The first step in the process that leads to a decision is observation of the real world through all available measurements, human inputs, and encyclopedic information stored in computers and in documents. These basic fragments of information are then expressed as digital representations called data so that they can be moved and managed easily. This is shown in Figure 2.

A very important factor is introduced at the time when we make a measurement and express it as data. The measurement itself is an observation of some phenomenon or multiple phenomena associated with a specific event or entity. The event or entity is fully deterministic, it is a specific and precise element in the overall state of the environment. However, the act of observing phenomena associated with that entity or event produces data that contains some element of statistical uncertainty. Even a human observation of an event or entity is a probabilistic determination of the state of the environment. The probability, or confidence level, of the observation may be very high, but we still need to recognize that the resulting data do not represent “ground truth”.

Data

- A Representation of Individual Facts, Concepts, or Instructions in a Manner Suitable for Communication, Interpretation, or Processing by Humans or by Automatic Means. [IEEE Definition Included in DOD TRM]
- Data Are <u>Numerical Representations</u> of Measured Phenomena [E.G. Sensor Reports] or Inputs Generated by Humans or Computers to Represent Some Quantifiable Aspect of an Entity, Event, or Environment.

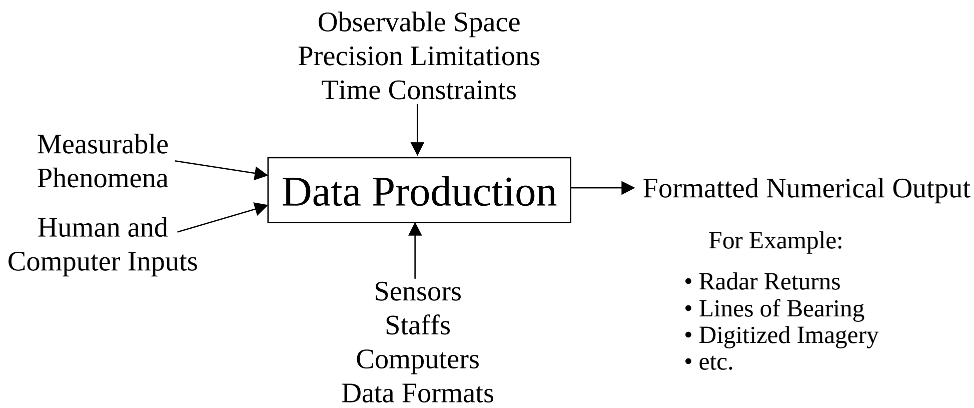

Figure 2. The Process Model for Producing Data

Thus, the initial inputs to the process are never fully deterministic. There is always some degree of uncertainty, ambiguity, and credibility associated with the data as it moves through the system. Bear this in mind as we progress through the stages leading to a perception and understanding of the situation.

The difference between data and information is very subtle but important. Data are numerical representations that can represent measurements or other inputs from human beings or automated systems. Data are the vehicle for conveying information either as unassociated fragments or as thoroughly processed and integrated products. If the data can be associated with a specific sensor or source, the meaning of that data becomes clear, and this transforms the numerical data into information that can be viewed and interpreted by human beings or automated systems. This corresponds to correlating the numerical data with some model of the sensor or source and the context to which the numbers refer. That is the basic essence of information.

For example, if a radar signal is reflected from an aircraft, the observation produces numerical data related to that observation. A model of the radar’s functionality tells us that the data define distance from the radar, size of the radar cross section that is indicated by the strength of the return, and other observables such as velocity component toward or away from the radar (for Doppler radars), and altitude (for height finding radars). When multiple, sequential radar returns are observed, the data can begin to include the full velocity vector. The radar data now is interpreted as information: a target of a certain size, speed, and location, moving through the airspace.

The process model for producing information is illustrated in Figure 3.

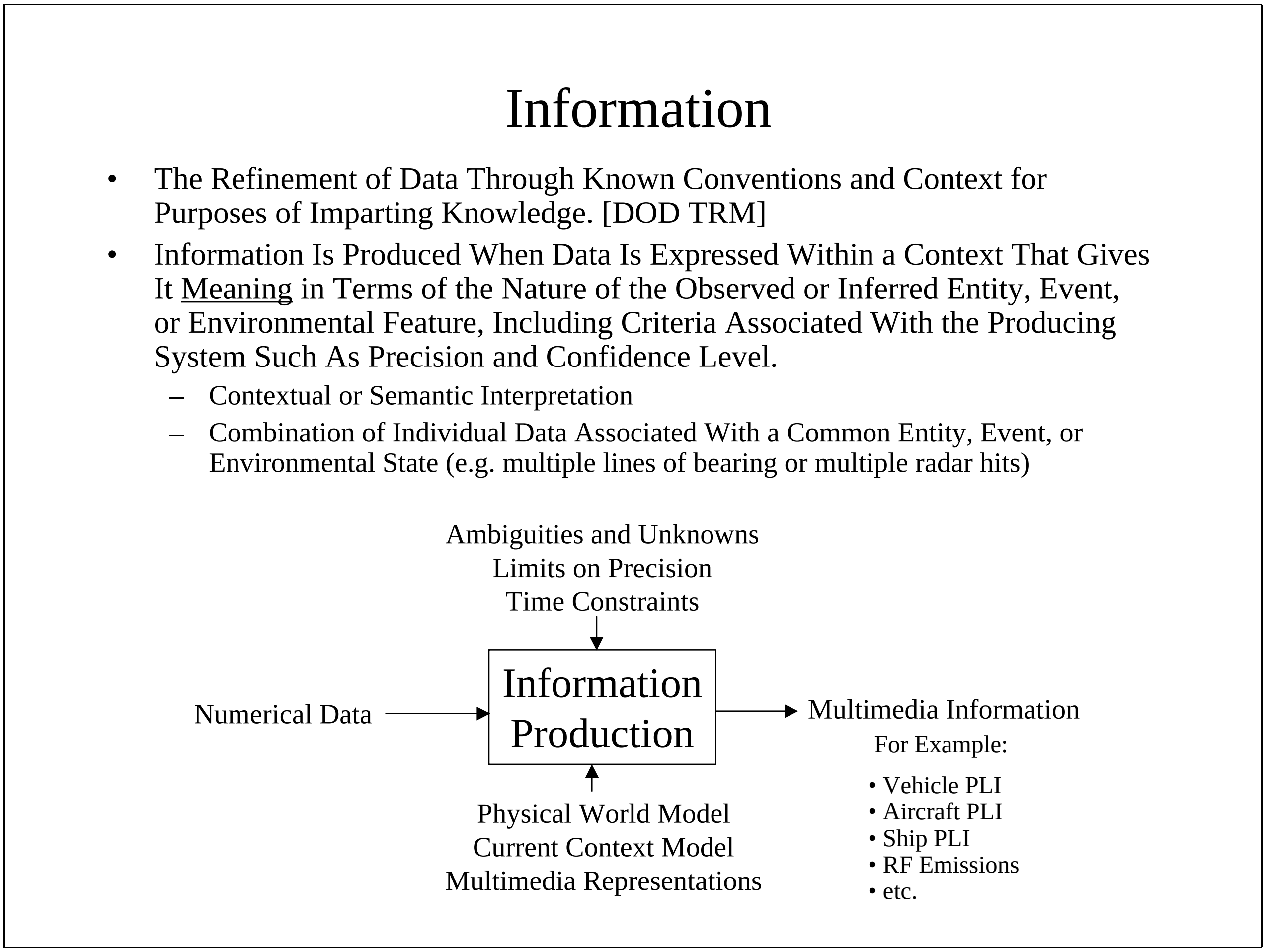

Figure 3. The Process Model for Producing Information

The next step in the process from observing to understanding is to convert the information to knowledge of the situation. This is the process that generates a perception of the situation.

Knowledge is produced when information is correlated with a model of the world and the current context. Consider the example of the radar return. If the information indicates an entity at an altitude of 10,000 feet and a speed of 500 nautical miles per hour, the “world model” tells us that it is most likely a fixed wing aircraft, and most likely a turbojet powered aircraft.

As more information is correlated with this radar return, we may know even more about it. For example, IFF returns may indicate that it is a friendly military aircraft, or other types of information may indicate that it is a hostile military aircraft. Each of these additional pieces of information can be correlated with one another, according to the current operational context.

Knowledge often builds from multiple possible interpretations, called multiple hypotheses. As we gather more information, we decide which of these interpretations to believe, and this produces our perception of the situation. We also recognize where additional information is needed, and this produces a directed search for additional information.

This process is illustrated in Figure 4.

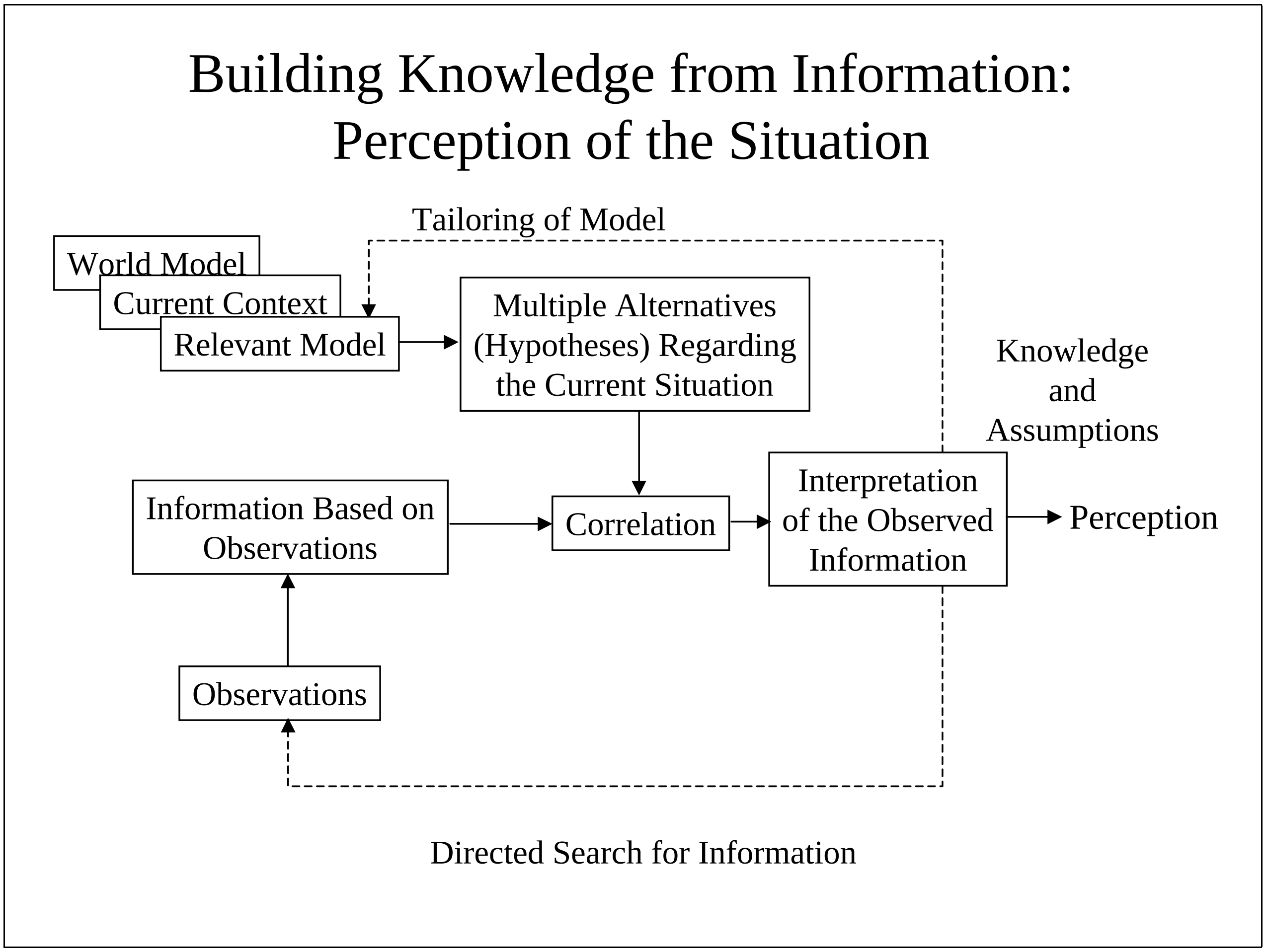

Figure 4. Building Knowledge and a Perception of the Situation

The production of knowledge from information is just one more step in correlating observations with our models of the world and the operational context. The principal factor introduced at this point in the process is the need to infer knowledge based on an interpretation of information and patterns of information within the framework of the models of the world and the context. This is where the human cognitive processes become important and where the partnership between the machines and the humans begins to become complex.

Inference and interpretation are based to a great extent on the credibility assigned to information. This is especially true when we have multiple hypotheses to consider and when the information and the world model and context model do not align perfectly with one another. Sometimes we can identify a key piece of information that will clearly differentiate among the hypotheses, but more often we can only develop our perception with an imperfect degree of confidence.

Any imprecision, ambiguity, or uncertainty in the source data will carry through the process and lead to corresponding imperfections in our knowledge and our perception of the situation. This theme, dealing with uncertainties and ambiguities, is one that lies at the heart of the decision support automation that we strive to perfect. Figure 5 shows a process model for producing knowledge.

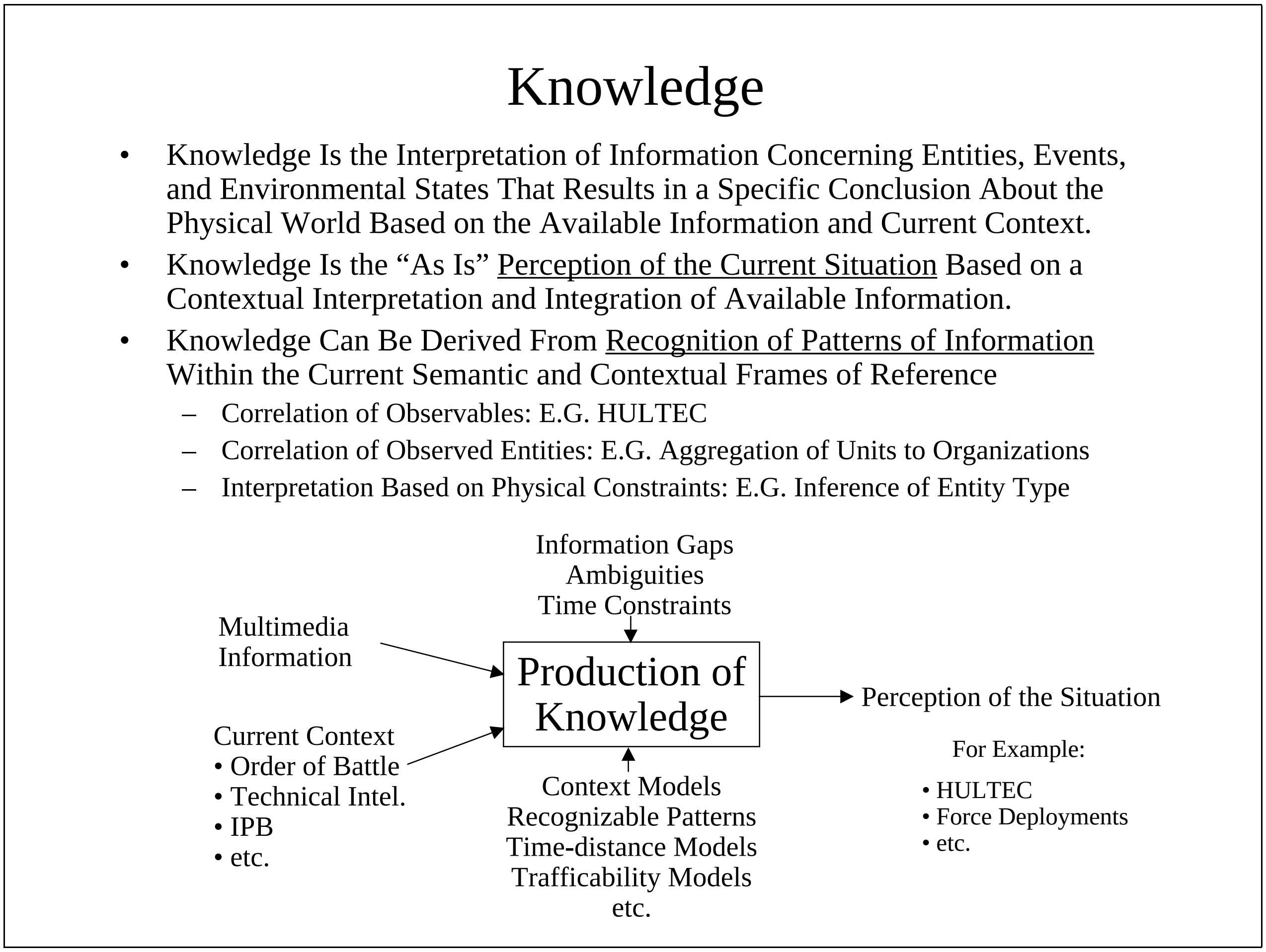

Figure 5. The Process Model for Producing Knowledge

We now introduce the notion of a "perception map" as shown in the diagram in Figure 6. We draw inferences from this base of knowledge, assumptions, and recognized uncertainties using judgment and experience. Human beings are very adept at correlating current patterns of information with past experience, especially when information is displayed as visual patterns that can be compared with previous experiences.

The perception map is a useful tool in understanding why we reach certain conclusions, why we are sometimes surprised by outcomes that are different from what we expected, and how we cope with uncertainties. In general, we strive to move from the "known unknown" sector to the "known" sector, to decrease the degree of uncertainty.

We make assumptions when we cannot resolve "known unknowns" that are essential to the perception. In those cases, we rely on judgment, experience, and intuition to define the assumption. The danger here is that we may forget that we based our perception on a critical assumption rather than a "known" set of information. We may also forget that a "known" set of information was actually based on imperfect data, as noted earlier. Consequently, even those things that we "know" are known only to some degree of confidence.

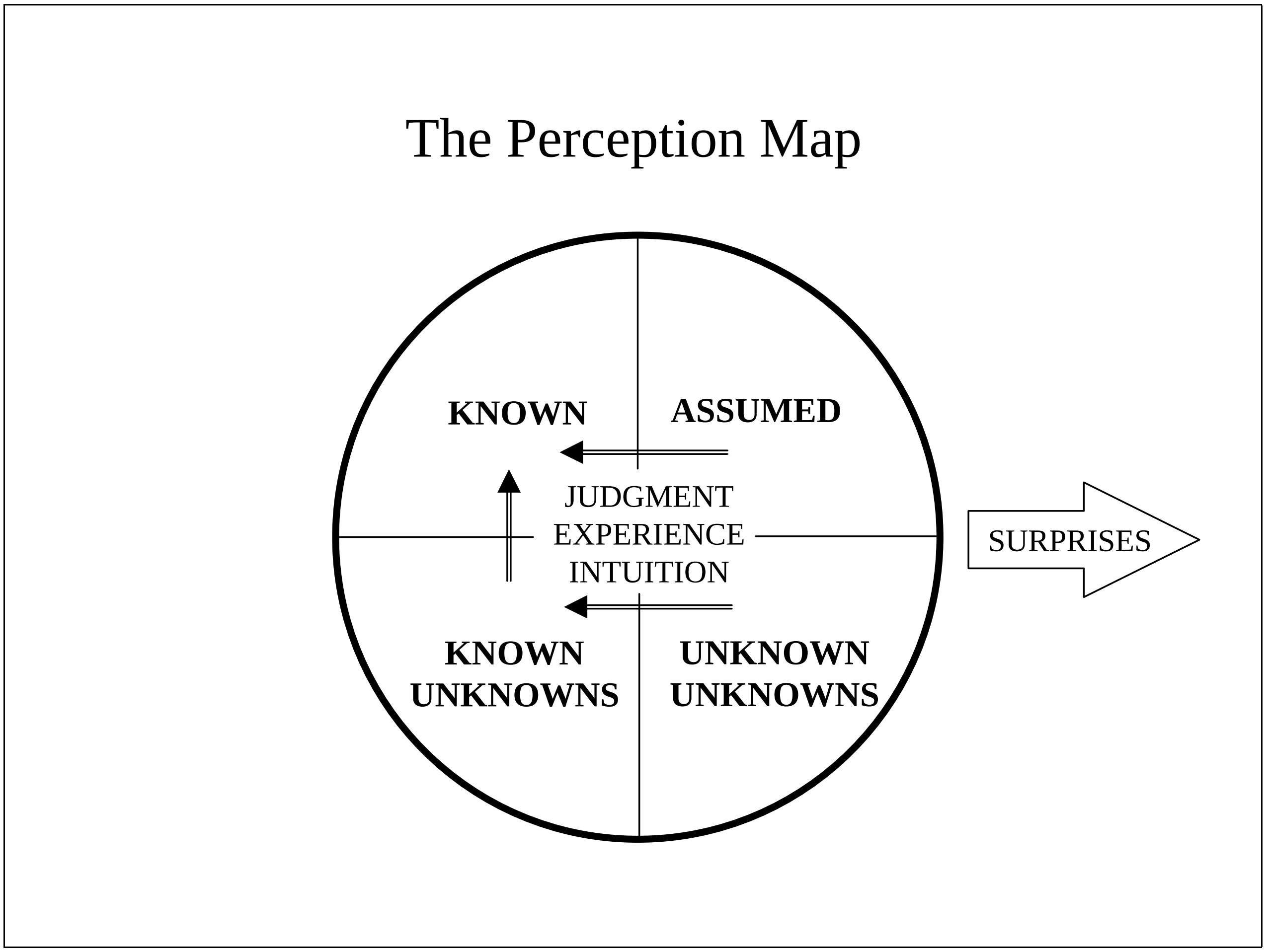

Figure 6. A Simple "Perception Map"

The "perception map" shows some essential features of the perception that leads to our understanding of the situation. The main factor is the inherently statistical nature of all the underlying information. We can know the situation only as well as we can make observations and interpret them. If observations are in error, we will have error in perceiving the situation. If models of the world or the operational context are in error, we will infer incorrect knowledge from the information. The previous example of inferring that an approaching aircraft is not attacking was based on an operational context of peace. A disastrous error in perception occurs when we think we are at peace but the adversary has actually made a transition to war and is launching a surprise attack.

While the "assumptions", the "known unknowns", and the imperfect "knowns" are certainly problems to be managed, the real villains in the perception map are the "unknown unknowns". Ideally, our information and our models of the world and context are good enough for us to identify all the critical "unknowns" and move them from the "unknown unknown" sector to the "known unknown" sector. Automated information systems can be powerful tools to help us do this, since they can track vast amounts of information and continually correlate and update relationships of information with world models and context models.

As noted in Figure 7, the mere fact that we know something does not mean that we understand what that knowledge means. We may know too little about a situation to make sense of it; we may be confronted with "facts" that appear to contradict one another and that tend to confuse us; or we may know too much and be distracted by interesting knowledge at the expense of focusing on the really important knowledge.

Understanding Is the Basis for the Decision

"I Don't Understand Everything I Know."

- This Statement Provides the Best Insight Into the Difference Between Knowledge and Understanding
- Information Systems Need to Help the Decision-Maker Understand the Situation, Not Just Know It
  - Situation Awareness Is Not the Objective
  - Situation Understanding Is Our Goal
- If I Know Too Much, It May Impede My Understanding of the Critical Information -- Information Overload, "Glare of War"
- If I Know Too Little, My Predisposition to Assume Things May Distort My Perception of Reality
  - Experts Have Greater Predisposition to Assume Than Novices
  - The Judgment and Wisdom That Comes With Expertise Also Brings Intellectual "Baggage"

Figure 7. The Difference Between Knowledge and Understanding

Another factor in reaching an understanding of a situation is the tendency of human beings to approach understanding from a predisposition to assume something about the situation even before any information is presented. Prejudgment is a fact that we need to recognize. When we have little information and little knowledge of the situation, most of our perception lies in the "assumed" and "known unknown" sectors. Our "knowledge" or awareness of the situation is driven by the assumptions and the recognition of gaps in knowledge. This can tend to cause our prejudgment to dominate.

The process for moving from knowledge to understanding relies very heavily on the judgment and experience of the human being and on his or her ability to correlate past experiences, training, and education with the current context.

Constraints on understanding the situation include gaps in knowledge, preconceived notions of what the situation should be, and time pressures. The fog and friction of war are clearly at play at this point.

Since judgment is a major factor in understanding the situation, the inputs to the process certainly include credibility factors related to the information that has been presented. Here we probably find a "feedback loop" back to the process that converted information to knowledge. If we think that we know something but cannot understand it, we will try to "rethink" the process from observed information to interpretation in terms of knowledge or perception of the situation. This is the typical question: "What's wrong with this picture?"

Figure 8 illustrates a process model for developing understanding from knowledge of the situation.

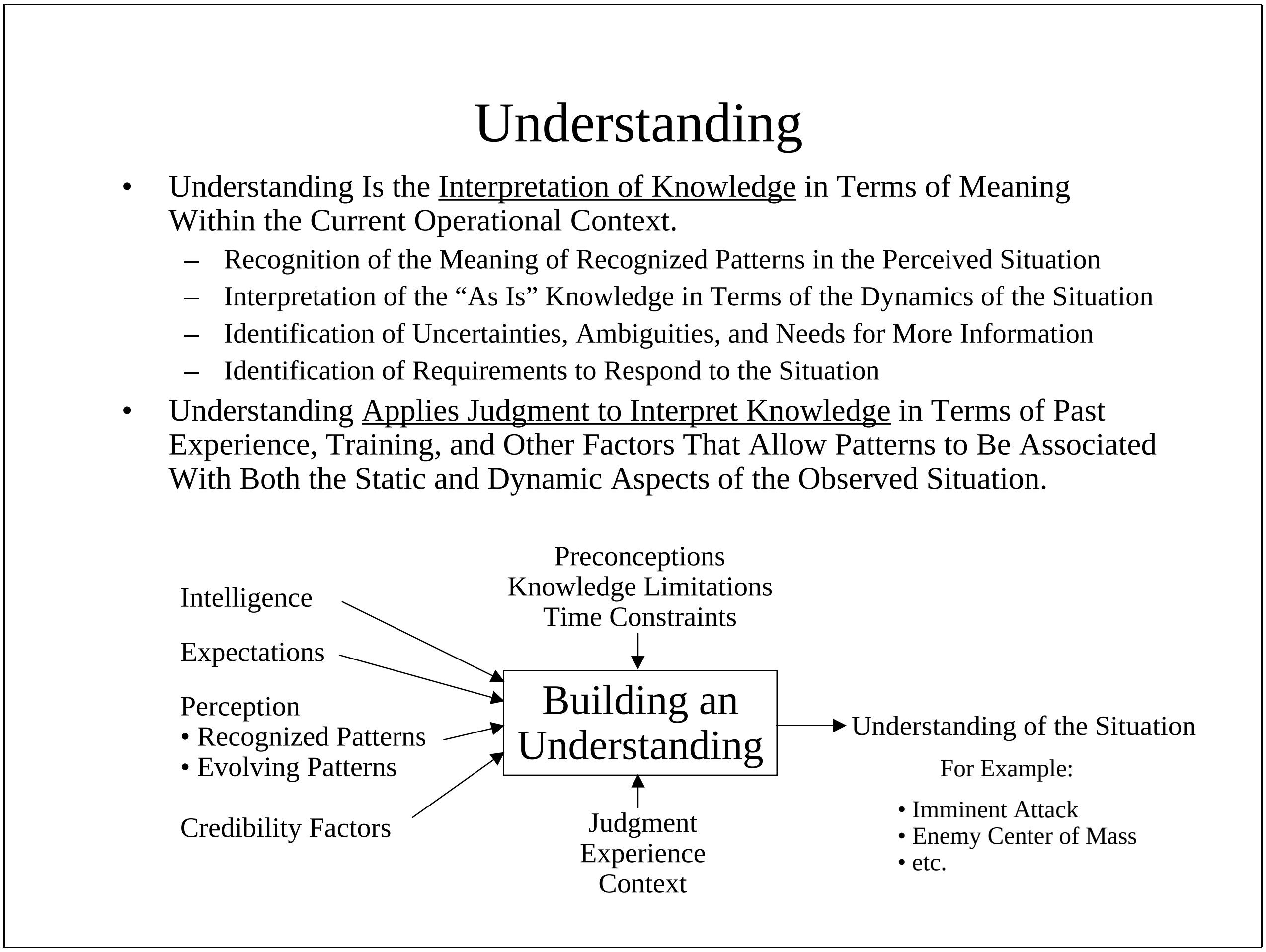

Figure 8. The Process Model for Building Understanding

Understanding is achieved through a correlation of the perception with the likely alternatives (multiple hypotheses) of what that perception means in terms of the current operational context. That correlation is then reviewed in terms of the context to produce an understanding of what it means. Note that the context model plays an important role in moving from information to knowledge (perception) and then to understanding. We continually "fine tune" our view of the information by matching our judgments, conclusions, and assumptions with the context model. That model itself grows and becomes more precise and specific as we use the process to update the model. As we know more about the situation, we adjust the context model, and we use that adjusted model to make further progress toward understanding. This is illustrated in Figure 9.

We also can fool ourselves by making errors in assuming or adjusting a context model based upon conclusions that were reached by using the context model itself. If we believe strongly enough that a certain situation exists, we may find evidence to reinforce that belief even when it is false. In engineering parlance, if we build an amplifier with enough gain and with fine enough tuning, we will see the signal we seek even if it is not there; we will have produced an oscillator instead of an amplifier. A basic tenet in deception tactics is to show something that is false but that is expected, thereby reinforcing a predisposition to reach wrong conclusions about the situation.

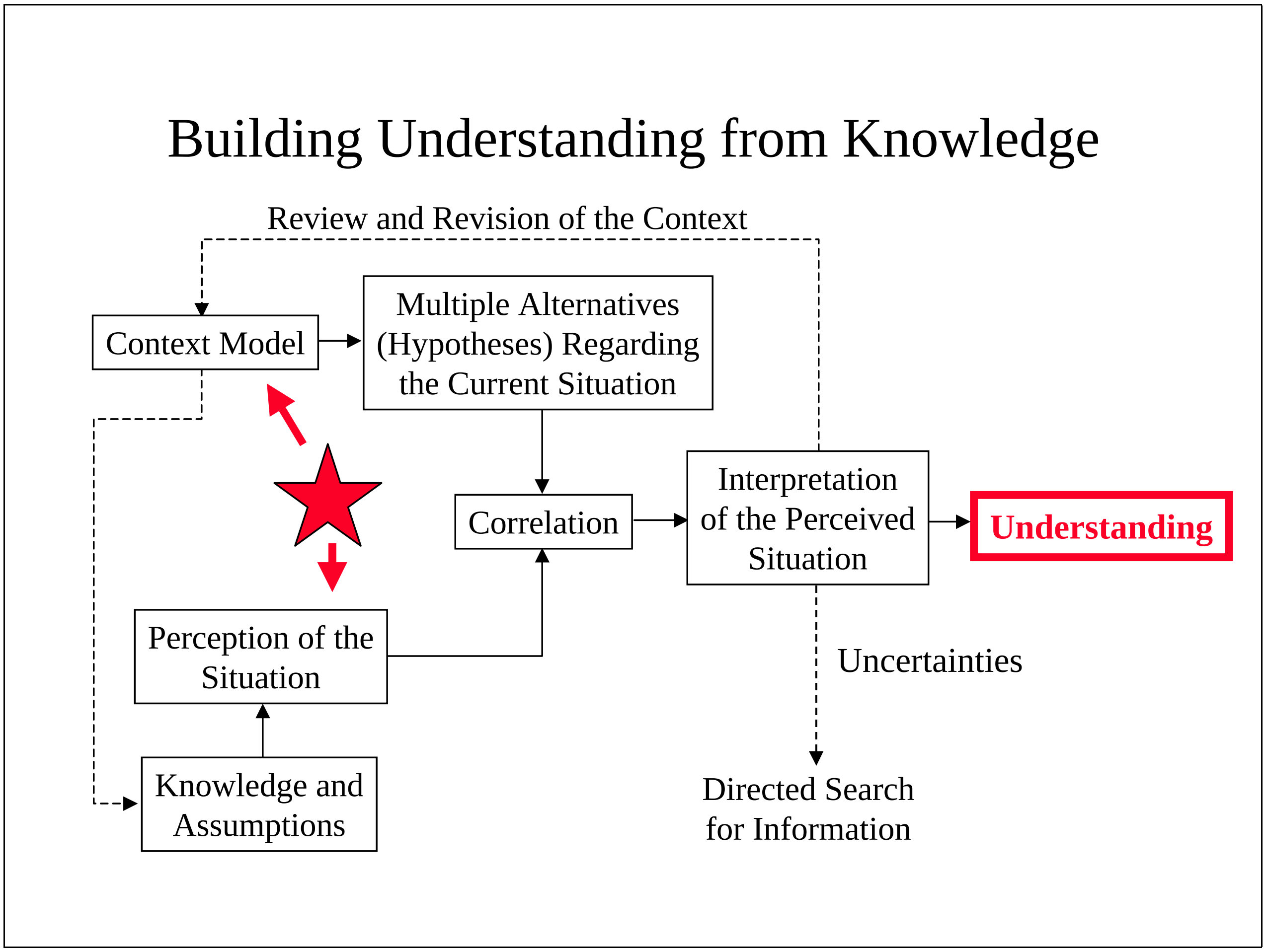

Figure 9. The Correlation and Feedback Processes that Build Understanding

To this point we have described the situational awareness and understanding process as one in which we correlate and integrate information to build a picture, or perception, of the situation. In a very simple situation, where information is clear, precise, and credible, that linear process of integrating and correlating may work, but in the real world, we often need to look into the details of the information or we need to acquire more information in order to reach conclusions. This is shown as the directed search for information in Figure 9. The search can be within the files of information that are already available, or it can be in the form of tasking for collection of additional information to resolve "known unknowns" or to confirm assumptions.

The need for examining specific details, also called "drilldown", arises when those details are essential for knowing how much credibility to assign to information or when we find that we may have to adjust our context model based on evidence. We often want to examine the evidence in detail before making that kind of adjustment. Drilldown is also needed when the automated processes or formal rules and algorithms for building knowledge produce results that are either unexpected, ambiguous, or confusing. By seeing specific pieces of information, we can often use human judgment and experience to do a better job of sorting through the information than the automated processes or the predefined rules and algorithms.

We now recognize that the "perception map" is not as simple as it first appeared. Recall that all the source data was statistical in nature. That is the unfortunate result of having to rely on imperfect measurements of phenomena to determine the state of the real world as noted earlier in this lecture. Consequently, even when we think that we know something, we only know it to a limited degree of accuracy and confidence.

Accuracy is something that we hope to have defined for us, based on the specific sensors and processors that deliver the information.

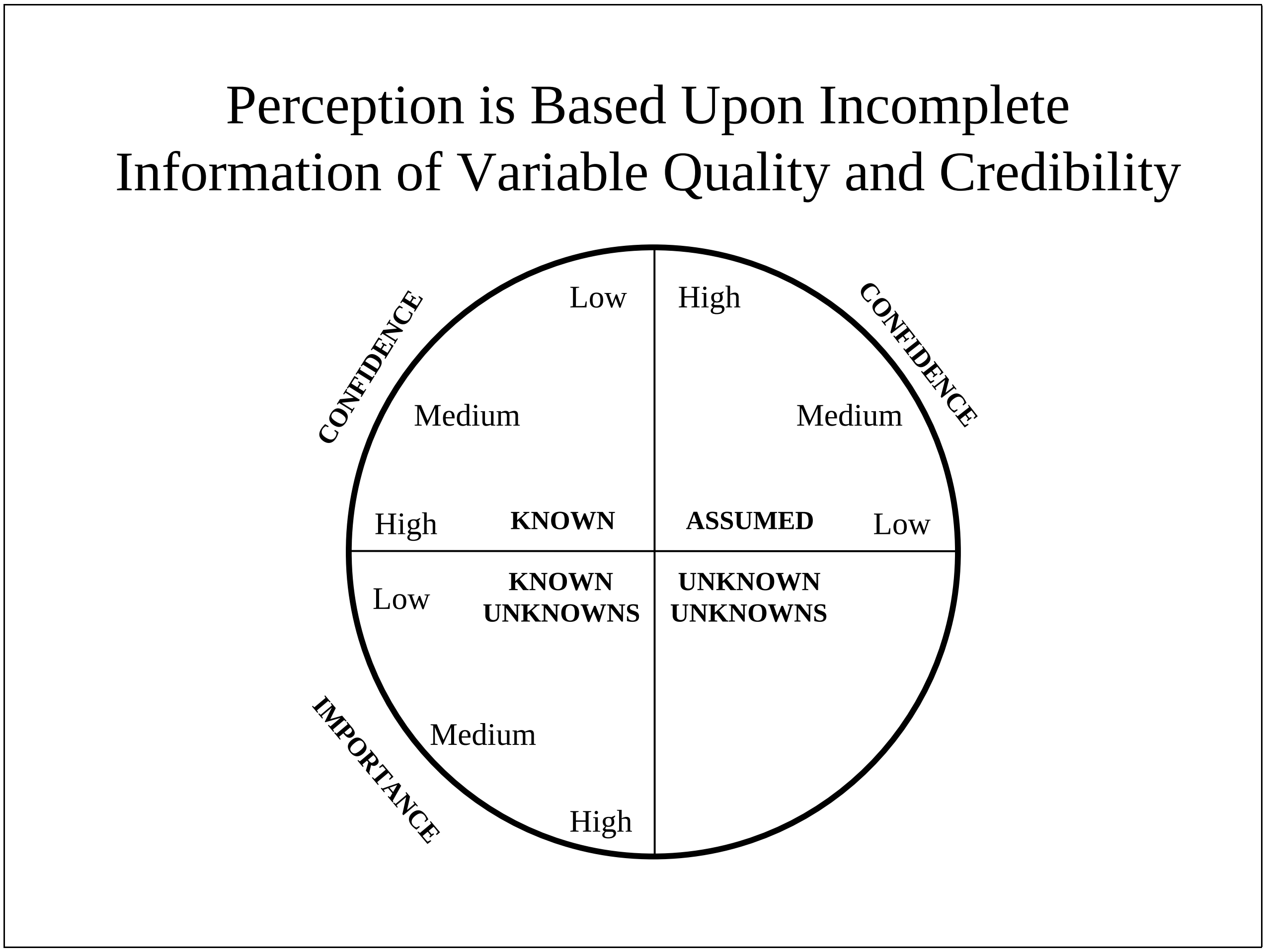

Figure 10. The "Perception Map" With Additional Details Related to Confidence and Importance

Confidence and importance are often difficult to determine and may be influenced by many factors, including the "strength" of the observed phenomenon, the experience of human beings who may have interpreted the observations, alternative hypotheses associated with the observations, known unknowns, and so forth.

The diagram in Figure 10 is not intended to be a precise description of how confidence and importance affect the interaction among known, assumed, and unknown aspects of the perception. It is only a notional diagram to help display how those factors affect our overall knowledge and understanding of the situation.

Understanding of a situation is, in many respects, like putting together the pieces of a puzzle. When we have all the pieces, when the fully assembled picture is one that is simple, and when each piece has parts of that picture that define where it fits, we can construct the full picture. However, when some pieces are missing or when we find pieces from other puzzles that look similar to one another (alternate hypotheses), we have difficulty constructing the picture. This is the challenge in understanding a complex situation with numerous alternative interpretations and with information that is statistical in nature and that has many missing pieces.

When confronted with such a challenge, we need to search for the information that is most critical to making the judgment and eliminating the unlikely alternative interpretations. This is called "value of information". We look for the missing pieces that will have the greatest influence on our determination rather than for less influential ones. We also look among the ambiguous pieces of information for the ones that make the greatest difference in our conclusions. This process of "diagnosing" the situation is identical to the process that a physician uses to diagnose a disease. This is illustrated in Figure 11.

Mathematical Rigor for Dealing With Relationships Among Uncertain Information

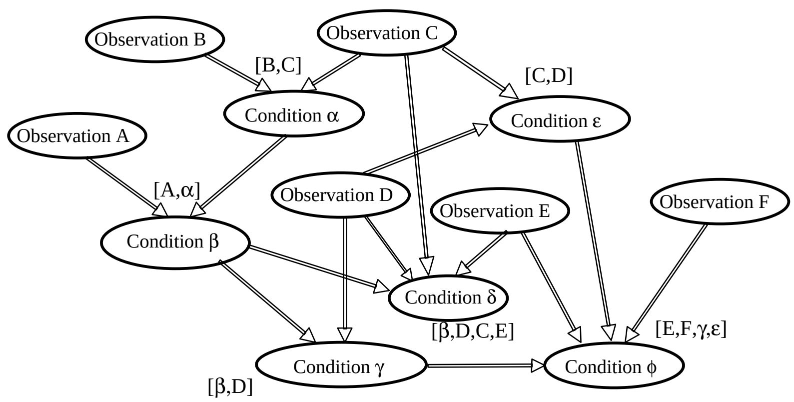

Figure 11. A Bayesian Network Formalism for Understanding a Set of Observations

As previously noted, the "diagnosis" of the situation rests on key elements of information and on relationships among them. Those relationships can be expressed as a network of nodes and links that show way that observed information can be traced to specific inferences about conditions or states of the observed system that can be made from the observations.

In this example, condition ϕ at the lower right hand corner of the network is distinguished from condition δ only by observation F. All other observations are consistent with both of them, even though the likelihood of the two "hypotheses" (i.e. condition ϕ or condition δ) may be different based on those observations. Furthermore, if condition δ does exist, then we can infer that conditions α,β, and γ also exist, since condition δ depends on observations that imply those other conditions too.

The question of likelihood is important in making the diagnosis. Bayesian nets allow the appearance of an observation or condition to be expressed in terms other than 100% or 0%. We can then produce a diagnosis that gives probability estimates for each conclusion based on the probabilities assigned to the source information. In the example of the radar return from an aircraft, the probabilities might be expressed as: (fixed wing 100%), (friendly 80%, hostile 5%, unknown 15%), (attacking 2%, not attacking 90%, unknown 8%).

The diagnostic net in Figure 11 showed that observation F was the most important piece of information to distinguish between conditions δ and ϕ. Therefore, if we need to make that distinction, we need to try to observe F.

The tactical forces deal with similar demands for distinguishing between various states of the situation. Is the enemy over that hill or has he moved to some other location? Am I about to be attacked? These questions demand focused observation to collect the most valuable pieces of information. It could be information that fills a void or it could be information to resolve ambiguous conclusions from information that we already have.

Sensors to collect such information are an important part of the situational awareness resources. They serve to provide many of the initial inputs during the Intelligence Preparation of the Battlespace (IPB) and through ongoing surveillance and reconnaissance, and they also serve to respond to immediate needs for information based on questions, issues, and problems that arise as we process information to obtain knowledge and then to understand that knowledge. Technology exists to build sensors that are suited to real time tasking and management by tactical forces, and this will help them penetrate the “fog of war” in a way that is responsive to their fine-grained, and locally focused needs.

Once information is collected and processed to provide a basis for understanding, we need to address the human cognitive aspects of the process. This means that we have to organize and present the information so that the human beings can use it effectively. Unlike computers, human beings do not simply manipulate numbers according to predefined mathematical rules. They are more adept at recognizing patterns of information and comparing them with past experience or training. Consequently, the way that information is presented needs to focus on displaying those patterns explicitly and without requiring the user to waste time and effort in peripheral tasks, such as extracting information from unformatted text. Figure 12 is notional, intended to make the point that pictures are better than words most of the time and that formatted presentations are easier to work with than simple narrative text.

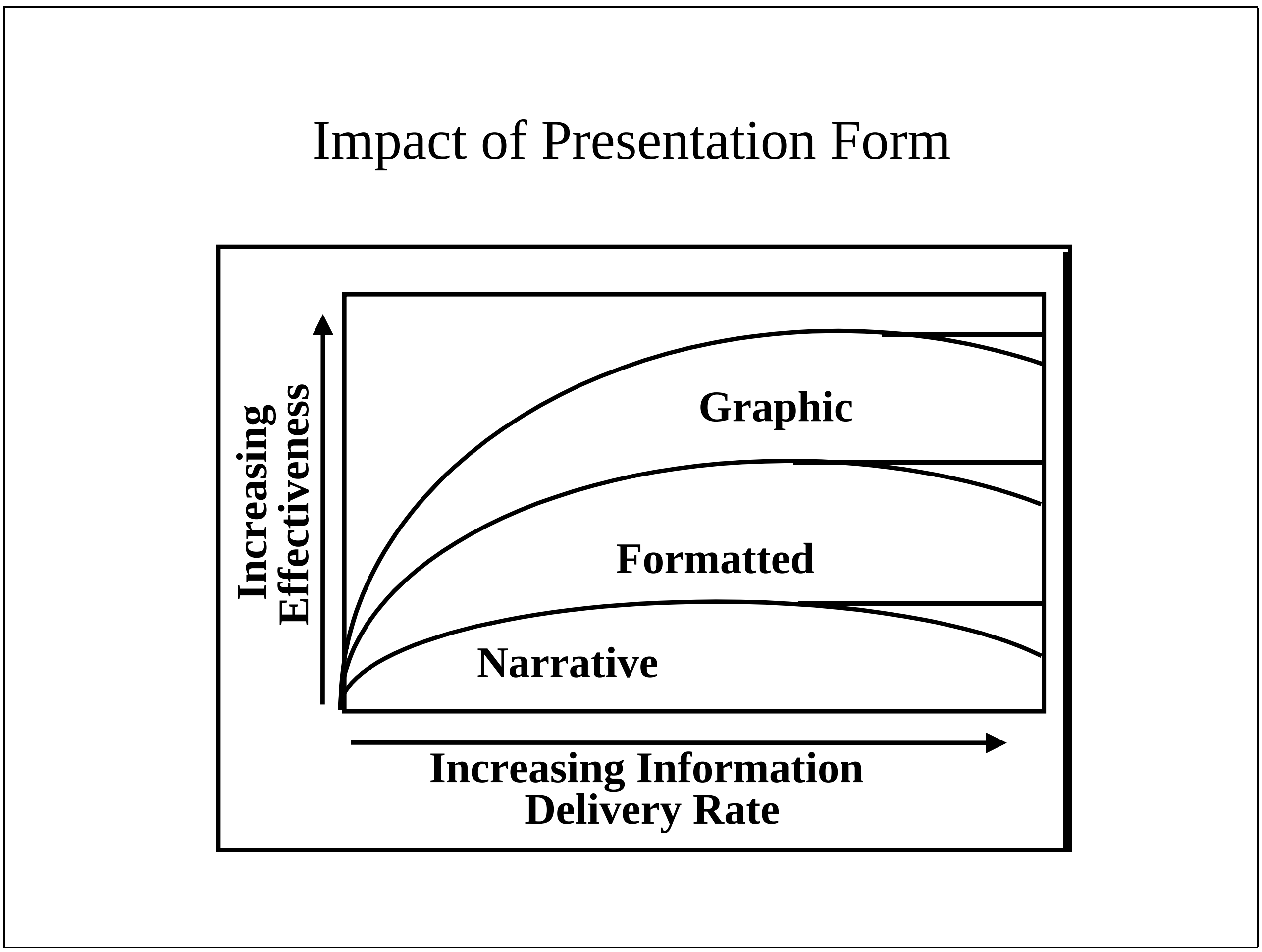

Figure 12. The Form of Presentation Impacts the Ability of Humans to Use Information

Modern command and control systems are built with these facts in mind. Most information is presented as some form of graphic display: a map, a bar chart, and so forth. This provides the overarching view and pattern; it establishes context and a framework for interpreting information; and it guides the users to areas where they may want to “drill down” to see more information. The next level, as they drill down, is often a brief, formatted display of amplifying data. Then, if they need more, they often can retrieve textual information or source data. The principle is first to present the overview, often general and qualitative, and to let the users determine how much they need in terms of actual numerical data or textual references.

Impact of the System Interaction Method

- The Best Human-system Interface Combines the Interactions With the Normal Process of Doing the Task
- Typing Is One of the Worst Forms
- WIMP - Windows, Icons, Mouse, Point-and-Click Is Better
- Embedding the Interaction Mechanism in the Task Material (E.G. An Active Situation Map or Display) Is Even Better
- Modern Systems Attempt to Offer a Human-system Interface That Is a “Metaphor” of the Workspace
  – The Desktop
  – File Cabinets
  – The Map
  – The Whiteboard

Figure 13. Implications of Various Forms of Human-System Interface

The summary in Figure 13 is based on experiences with real world experience and is manifestly evident to anyone who has worked with automated systems. Any requirement to use human intellect to punch keys or read narrative text is wasteful. Efficiency is gained as the human-system interface becomes more oriented on the environment in which information is appraised and manipulated. If the workspace is structured as a map with overlays and icons, the WIMP interface works well. If the icons can be constructed with summary information displayed explicitly and drilldown information embedded and easily accessed with point-and-click, the interface becomes extremely useful.

Other features can be added to the human-system interface to reduce the burden of accessing and manipulating information. Some of these features can be built as “intelligent” software agents that can be tasked to do some of the routine and burdensome tasks. For example, an agent can be used to track specific types of information and alert the human operator when certain predefined conditions are observed. Other, more complex agents can infer need to alert the human operator when specific patterns of information are observed or when ambiguities and contradictions are observed. Speech interface is also a feature of some new systems, currently in the commercial world but making their way into military command and control systems. We can expect significant advances that begin to provide actual human-computer dialog and multi-agent cooperative tasking.

Figure 14 shows an integrated information and multi-agent command and control tool that was built by Logica UK for a U.S. Marine Corps and Navy Advanced Concept Technology Demonstration (ACTD) called "Extending the Littoral Battlespace" (ELB). The Logica system was an adaptation of work of a European consortium led by Logica. The display and human-system interface embody many of the principles discussed previously.

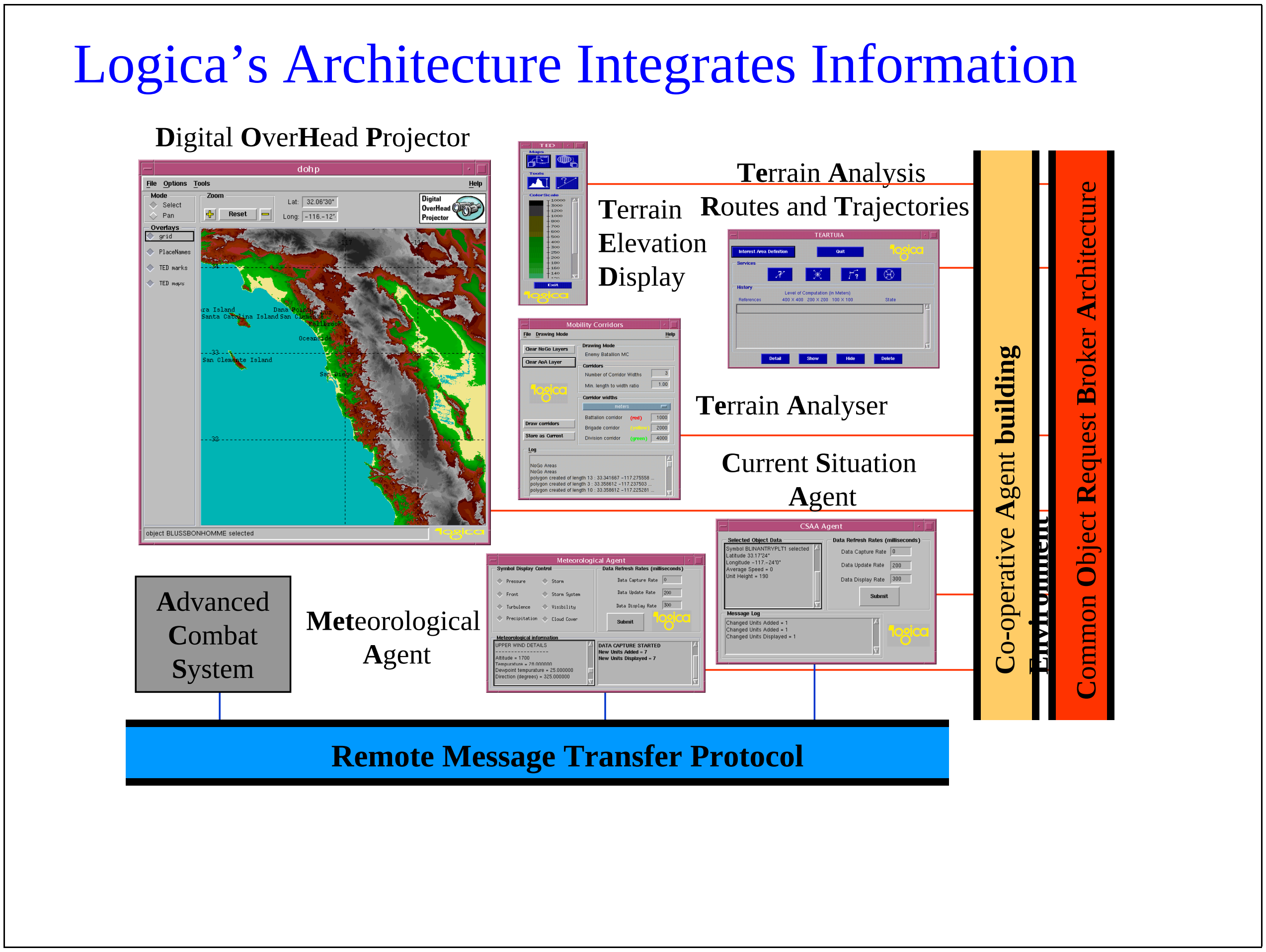

Figure 14. An Implementation of Integrated Information Services

The workspace metaphor is a map. This is a very common preference for operational and tactical command and control functions. Logica provides overlays for various types of information, such as tactical situation, meteorological effects, and terrain reasoning. The overlays are managed by software agents, and each overlay can be turned on or off, depending on the amount of information that the human operator wants to see at the time. This provides user control over the degree of integrated information that is displayed. Some of the agents are very simple ones that just place icons or other information on the overlay. Others are more complex and do tasks such as terrain reasoning, line-of-sight calculation, and so forth. The Logica interface and the underlying agent-oriented environment provided a very powerful tool for helping the users work with a network of computers that contained a very broad and complex set of information. By using the power of the interface and its tools, the user could construct precisely the display that suited his or her task.

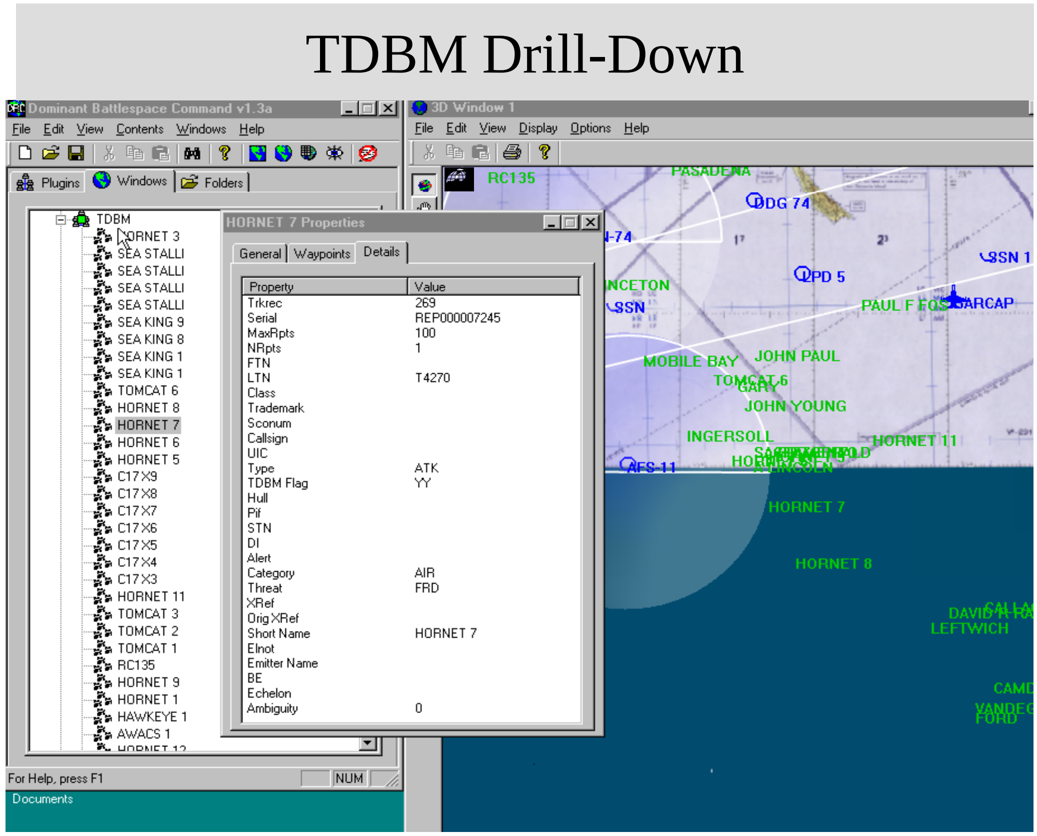

Figure 15. A Representative Display of Tactical Situation Data

The Office of Naval Research is managing a program called Dominant Battlespace Command (DBC). It is being executed by Concurrent Technologies Corporation, with the objective to build visualization environments that interface with currently available command and control information systems to improve a commander's ability to comprehend the battlespace situation and make decisions quickly and effectively.

This DBC display shown in Figure 15 is connected to the track data base management (TDBM) software in the Global Command and Control System (GCCS). The interface allows the users to see both the overall tactical situation and selected details (drilldown) of specific information for each entity in the track data base. This type of drilldown capability is a standard feature in GCCS and many other command and control systems that are currently in use. It is an important way to present the overall pattern without saturating the user with too much detail, and still allow the user to obtain those details when needed.

The map display is really a "rich meta data" display rather than a display of actual data. It is like a merger of the "index" and "annotated outline" of the content in the data base. It provides an overall sense of the situation and the relationships among entities and events that have been observed. When we need the actual data, it provides pointers to the selected information.

Users of the track display may want to see specific entities and not others. This is especially important when the display is cluttered with objects that are not of immediate interest. Filters provide a capability to select the types of entities that are shown and the ones that are maintained in the background. This is another important capability provided by systems such as GCCS.

When we use filters to declutter a display, we need to be careful to assure that the hidden entities are called to our attention if necessary. Otherwise, we can reach conclusions about the overall situation and take actions that may be in conflict with the actual state of the battlespace. This can cause unintentional “blue on blue” or “blue on white” engagements or dangerous conflicts of fires and maneuver. This is where software agents can be established to monitor the hidden entities and alert the users when certain criteria are met.

The DBC display environment and many other command and control displays also allow users to select the specific view of the situation that they need at the time. In the case illustrated in Figure 16, the user has selected the tactical tracks from the GCCS track data base overlaid on a two dimensional map.

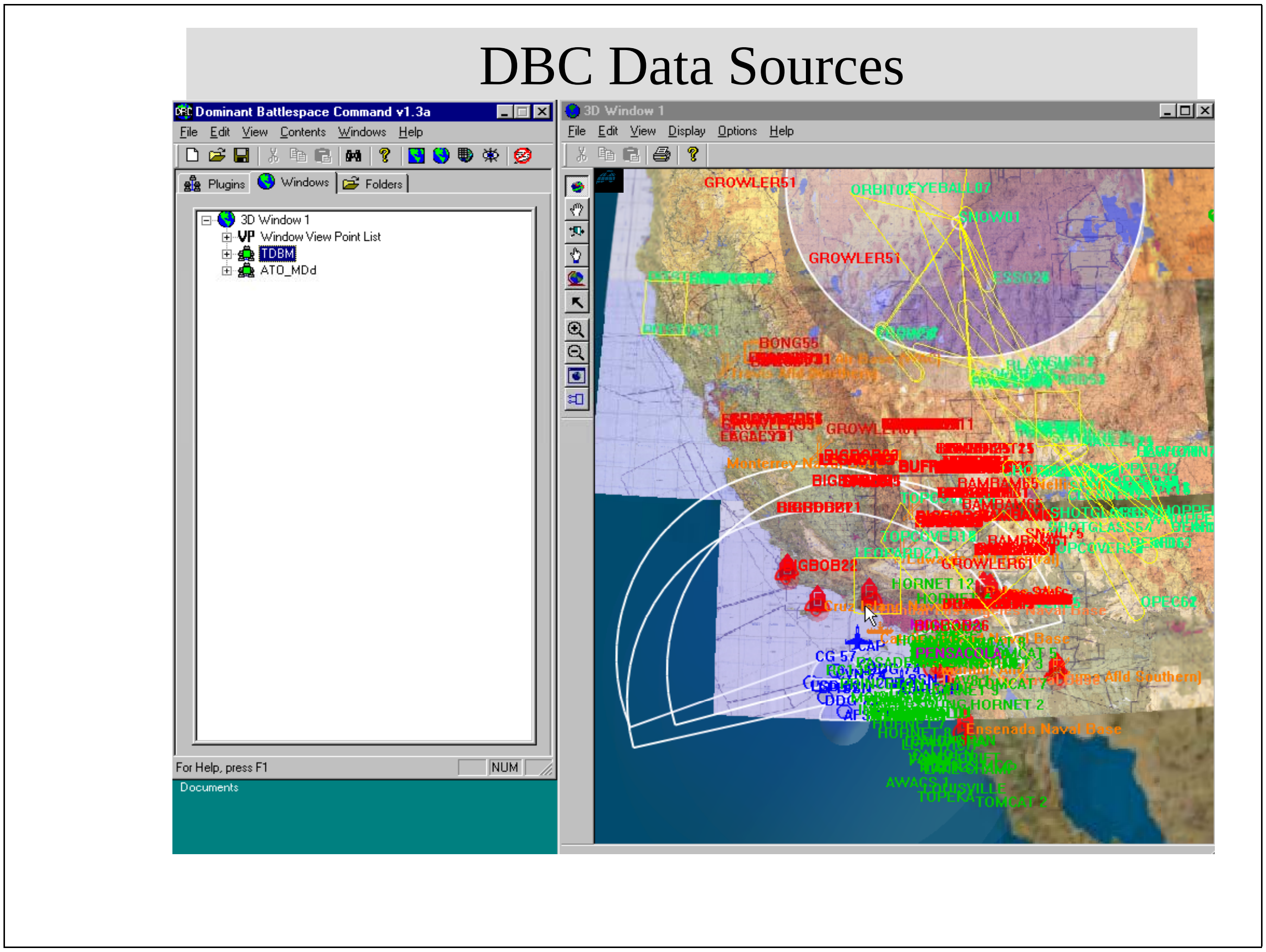

Figure 16. Selection of Data Sources to Be Displayed

Systems such as this present the users with an active display of their choice, an ability to drilldown for detailed information, and a list of other available displays that are reached with a simple point-and-click. Consequently, the users have available to them a very rich source of situational information, with an ability to structure the view of that information to suit their needs.

Another important visualization tool is the explicit display of surveillance and tracking coverage areas or volumes. This allows us to recognize regions where unknown information may reside. It helps convert “unknown unknowns” to “known unknowns” so that we can deal with them. The display in Figure 17 focuses on the coverage of a U2 reconnaissance aircraft as it flies through the battlespace. The “fan” extending from the U2 toward the coast shows precisely where the U2 sensors are looking at the time. This allows the operators to know what areas are being covered and what areas are not covered.

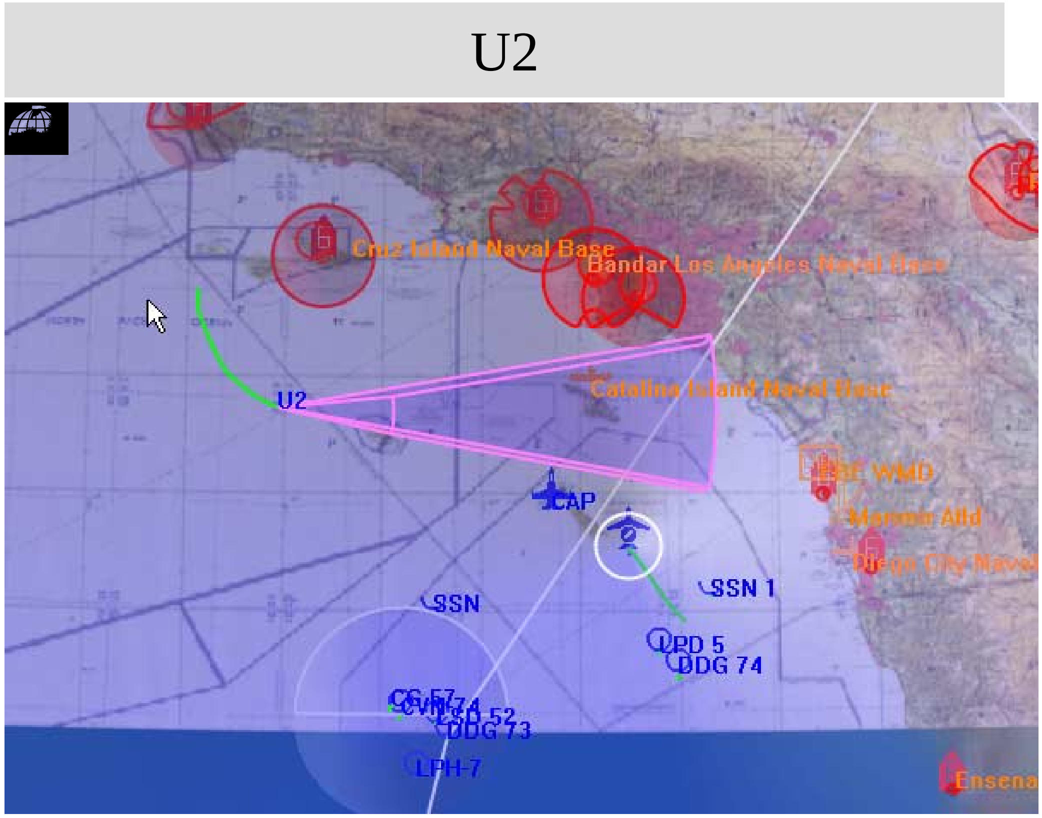

Figure 17. Visualization of the Sensor Coverage of a U2 Surveillance Aircraft

The information in this display can also be presented as a three dimensional perspective display if that suits the users. Other options for the presentation include a true 3-D display or an immersive reality environment. The DBC program is experimenting with all of these types of user interfaces to determine how each one could contribute to situation awareness and understanding for different types of tasks and operational situations.

We conclude the first part of the two-part lecture with the summary in Figure 18.

Situational awareness must always contend with “fog of war”. As we are able to observe, process, and disseminate more information about the battlespace, some of the fog will be removed, but we can never see true “ground truth”. Uncertainties and ambiguities will always remain and must be tracked and managed. In fact, as we bring more sensors to bear and connect more users with one another, the potential for ambiguities and contradictions increases. We see this in some of the current tactical data link systems where the number of unresolved duplications of track and target data increases as we add more sensors. Consequently, we have greater need for automated tools and models to resolve ambiguities and contradictions.

The second problem area that we need to address is what can be called the “glare of war”. This is the overabundance of information that is delivered to the users and that can obscure the information that they actually need. The fact that information will now come in many different forms and at different rates compounds the problem of presenting an integrated, coherent, and relatively simple picture to the human beings so that they can recognize the important patterns and not be distracted by irrelevant information. We need to make sure that additional information helps their performance.

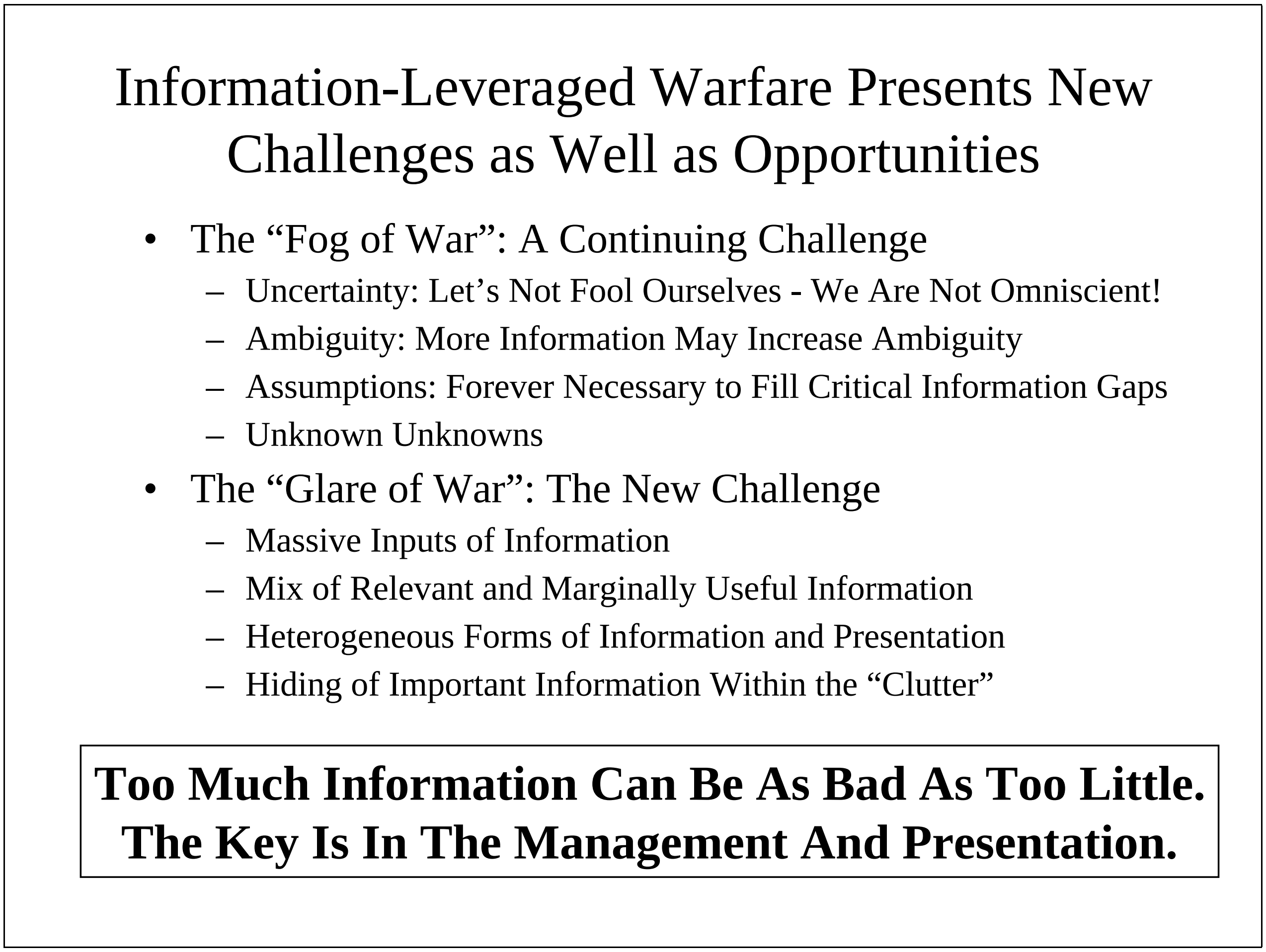

Figure 18. Summary: Challenges and Opportunities in Information-Leveraged Warfare

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Tactical Decision Making: The Interaction of Human Perception and Judgment with Automated Information Processing and Presentation

II. Decision Support

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Modern information technology can improve situational awareness and understanding far beyond the traditional "fog of war", but these improvements are useful only if the operators can apply that awareness and understanding to reach decisions better and faster than before. The goal is to achieve "decision superiority" not just information superiority.

In the complex and fast-paced battlespace of the future, humans will rely more and more on information technology to deliver knowledge and to assist them in using that knowledge. As the range, speed, lethality, and cost of weapons increase, the human cognitive processes will have to be augmented by rapid, automated appraisal of the situation and the available courses of action. The decisions will have to be reached by a mix of human and machine reasoning, including a theater-wide perspective as well as a local perspective. This presents new challenges for the system developers and the operational concept developers, and those challenges are being addressed in a number of development and experimentation programs.

This discussion extends the prior consideration of situational awareness and understanding to address the use of that awareness and understanding to determine the decision.

Paper presented at the RTO SCI Lecture Series on "Tactical Decision Aids and Situational Awareness", held in Amsterdam, The Netherlands, 1-2 November 2001; Sofia, Bulgaria, 8-9 November 2001; Madrid, Spain, 12-13 November 2001; Maryland, United States, 19-20 November 2001, and published in RTO-EN-019.

Three Types of Decision Drivers

- Procedure
  - Decisions That Are Made According to a Schedule
  - Examples: the Daily Briefing to the Boss, the ATO, Ordering Lunch
- Need
  - Event-driven
  - A Decision Must Be Made to Respond to the Event
  - Examples: Destroy Incoming Missile, Steer Car Around Pothole
- Opportunity
  - Event-driven
  - If a Decision Can Be Made Quickly Enough, Some Unanticipated Gain May Result
  - Example: Enemy CP Sighted, One-day Price Reduction

Figure 1. Reasons for Making Decisions

We make decisions for one of three reasons as indicated in Figure 1.

An important goal of modern knowledge superiority or decision superiority is to allow us to move from procedural decision making toward opportunistic decision making. This allows us to dominate the battlespace and to take the initiative away from our adversary. We still need to be able to respond to events beyond our control, but we strive to minimize this type of reactive posture and move as much as possible toward a proactive posture.

Procedural decision making, on the other hand, is largely decoupled from the real time battle and is not well suited to a dynamic battlespace.

How can we take advantage of improved situational awareness and understanding to achieve effective capability for both proactive and reactive decision making and to move away from the rigid process-driven decisions? That question is the focus of this part of the two-part lecture.

As a first step, let us look at the role that information plays in the decision process. We take it on faith that more information is good, and less is bad, but that may not really be true. If additional information causes a cluttered or confused view of the situation, then we are better off without it. We need the "right" information, not just all available information. This is indicated in Figure 2. The main point to bear in mind is that the information is presented to the user for only one purpose: to assist in understanding the situation and responding to it. Modern command and control information systems are focused on that objective and include a blend of technology and human factors that support the cognitive process leading to decisions.

The Use of Information in Decision-making

- The More We Know About the Situation, the Better Is Our Ability to Make a Good Decision
  - Not Really True: the More We Understand, Not the More We Know
  - Too Much Information Can Be Worse Than Too Little
  - "Glare of War" Combined With "Fog of War" Can Be a Problem
- Decision-support Involves the Use of Information to Support Deliberate Action
  - The Most Important and Often Overlooked Aspect of Information System Design and Operation
  - If We Cannot Act on the Information, Why Bother With It?
  - Timeliness and Relevance Are Key to Success

Figure 2. The Relationship Between Information and Decision-Making

The previous lecture on situational awareness and understanding discussed a simple model for decision making. We saw that perception is the basis for understanding and that perception was a complex mixture of knowledge, confidence, experience, and context.

A major deficiency in that model is that it implies that understanding leads directly to decision making. That is not correct. The decision maker must first interpret his or her understanding as a set of alternative courses of action. Then he or she must be able to select the best course of action from those alternatives.

Clearly, this progression from understanding to decision involves a relatively complex interaction of the user's perception, his or her experience and judgment, and a further understanding and interpretation of objectives. As we move away from the rigid process-driven decision making and toward more dynamic decision making based on real time situational understanding, those parts of the process that rely on interpretation and judgment become very important. The decision maker will need to be able to take initiative to interpret guidance, constraints, and operational objectives in terms of the immediate situation in the battlespace. The tactical decision aids will need to provide support attuned to those judgmental and inferential processes.

Current command and control theory lacks a clear definition of the part of the cognitive process between understanding and decision. It is sometimes called "wisdom", but that term does not really describe it. Perhaps a better term would be "appreciation" or "military appreciation". That term is a traditional one that means a comprehension of the implications of the situation upon an ability to achieve operational objectives. This is precisely the type of comprehension that builds upon understanding to reach the decision, so we have good reason to adopt it and insert it into our model.

The model for decision making can now be redrawn to include "appreciation" as shown in Figure 3. Appreciation is "fed" by understanding; supported by experience (including judgment and wisdom within the brain of the decision maker); and guided, focused, or limited by operational objectives, priorities, doctrine, and so forth. The output of appreciation is the judgmental determination of the course of action to be taken. This is the decision.

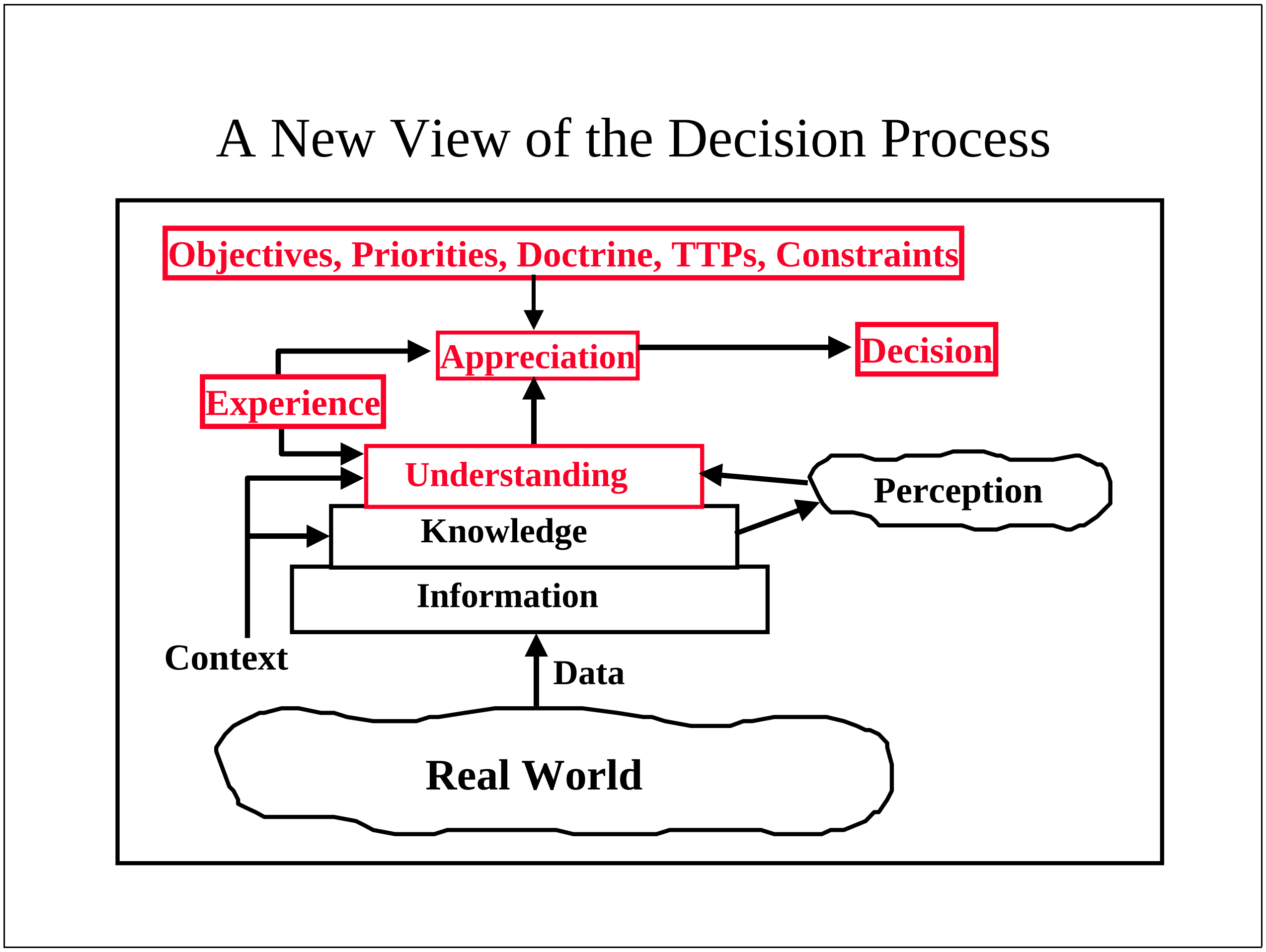


Figure 3. Basing a Decision Upon an Appreciation of the Situation

Tactical decision aids will need to help the decision makers correlate all of these factors quickly, unambiguously, and with sufficient confidence to make the decision. One of the major complications at this stage is that the decision maker is being asked to make a judgmental decision with potentially lethal consequences and that the decision needs to be based on a perception of the situation that is statistical in nature. We do not have the advantage of being able to feed deterministic inputs into a well defined algorithm to produce a deterministic result. Instead, we have to use a perception of the situation that includes information of varying degrees of clarity and credibility, and we have to use a process that is largely judgmental to decide on a course of action that appears to satisfy the objectives, rules of behavior, and constraints.

A process model for the development of a military appreciation is illustrated in Figure 4. This is a notional model for the development of the military appreciation. The input information is on the left hand side, feeding into the process node. The supporting resources, judgment and vision, are shown feeding in from the bottom. The constraints feed in from the top; and the output is to the right.

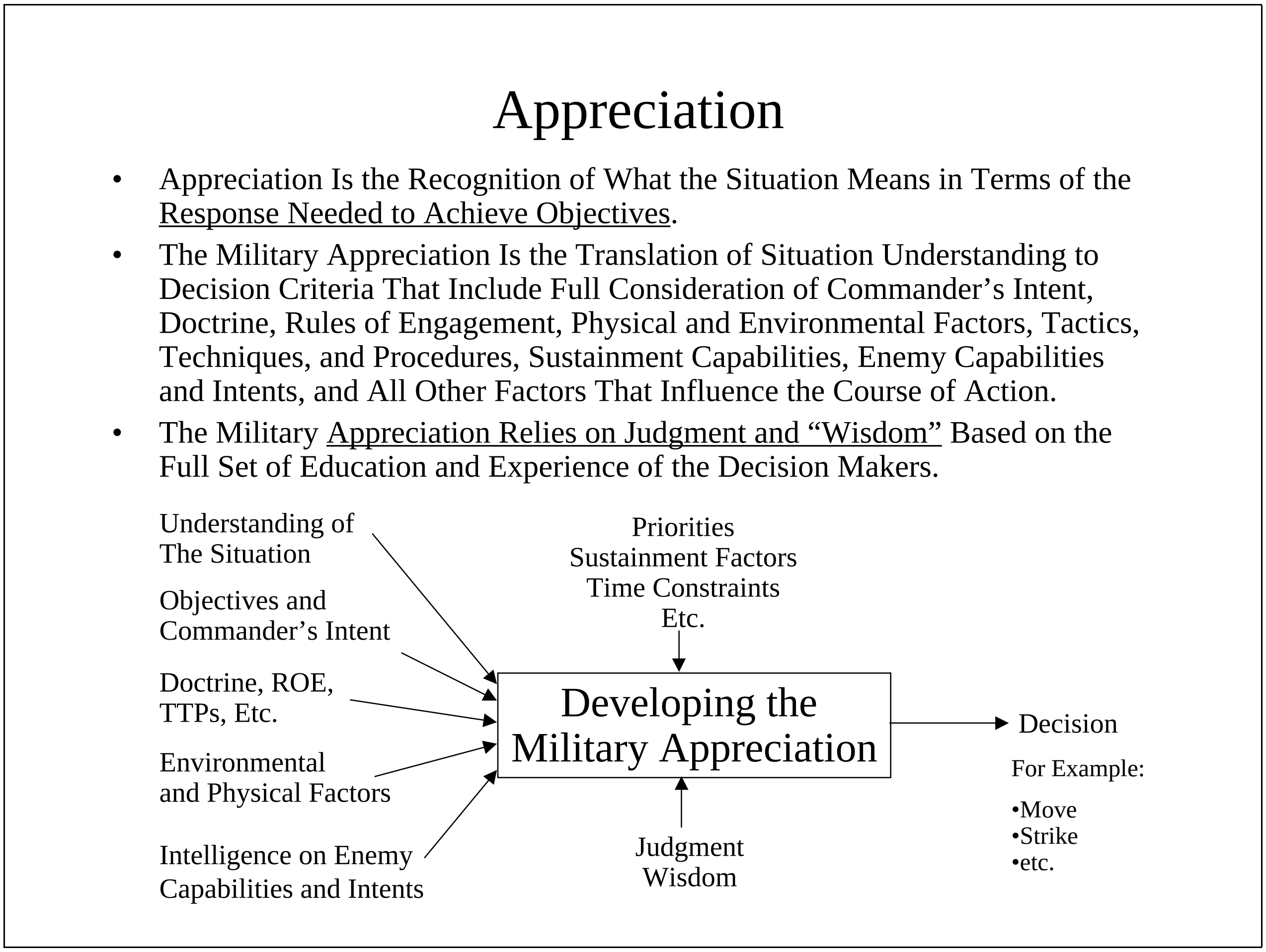


Figure 4. A Process Model for Developing the Military Appreciation

The current state of the art in information technology can do quite a bit to help decision makers appreciate the situation, but true "artificial intelligence" remains in the realm of science fiction. Computers are very good at adding, subtracting, and comparing numbers, and they can execute processes with mathematical precision, but they do not think. If the decision making is of a form conducive to algorithmic computation, such as development of a fire control solution, computers are far better than people. If the decision making requires judgmental inferences and tradeoff in a complex situation, the human beings probably outperform the computers. Such is the case with most tactical decision support systems. The human being is the decision maker, and the computer is the support tool. Sometimes it can actually recommend a course of action and develop an initial draft of the plan, and at other times it simply does the bookkeeping and arithmetic.

Collaboration among human beings is often required when the appreciation requires different sets of experiences and skills. For example, an air strike on a ground target may require judgment on weapons effects, threats, weather, and so forth. In those cases, collaboration among experienced people is needed. This can be either in a single physical location or distributed across a network. Modern technology gives us the ability to construct such distributed virtual staffs and to have opportunity to use expertise from the finest minds available rather than just the collocated staff.

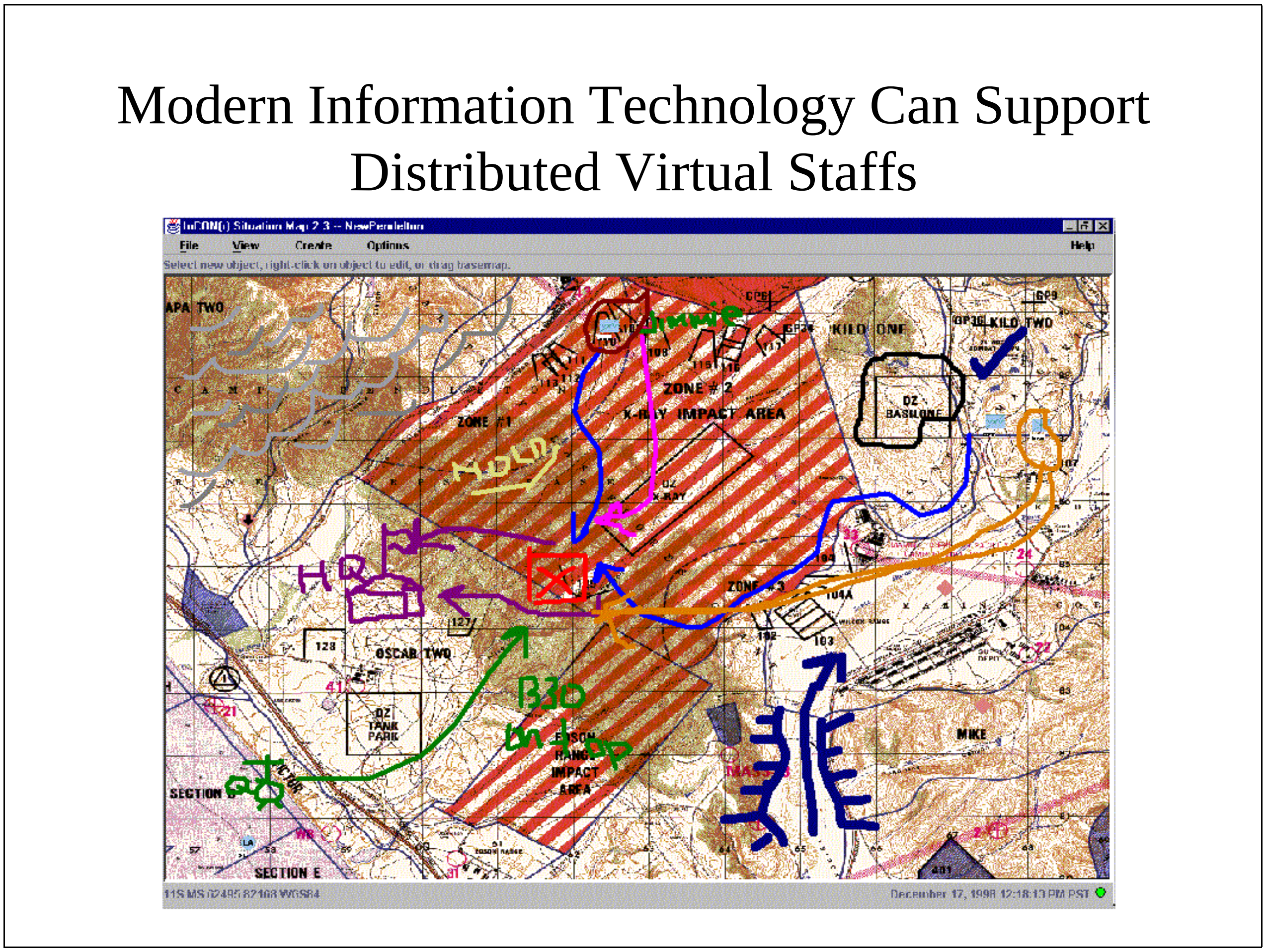


Figure 5. A Collaborative Map Display With Overlays Managed by Multiple Users

Figure 5 illustrates a form of distributed collaboration that was used during the “Extending the Littoral Battlespace” Advanced Concept Technology Demonstration (ELB ACTD) in 1999. The application was a commercial product called CU-SeeMe. It allowed users at various locations to draw on a shared overlay superimposed on a map of the battlespace. The application was hosted in standard desktop and laptop PCs, connected with one another through the ELB Wide Area Relay Network (WARNET). In this way, the users at different locations could work together in real time to develop the maneuver plan. This is called “synchronous collaboration” because all the users are collaborating with one another at the same time.

Another form of distributed collaboration is called “asynchronous collaboration”. In this case, each user contributes to the product independently, either by placing products on a shared electronic table or bulletin board, or by e-mail or some other means of information transfer. When we use e-mail to coordinate drafts of a paper or briefing, this is asynchronous collaboration.

Distributed collaboration during the ELB ACTD demonstration in 1999 included tactical warfighters in a variety of environments, not just people at consoles in command posts or on ships. Figure 6 shows a few of the environments during that demonstration. The command center was onboard the USS Coronado, at sea off the coast of San Diego, California. The furthest reach for the airborne relay network (the WARNET) extended to hand held computers and mobile equipment in HMMWVs in Yuma, Arizona. Synchronous collaboration using CU-SeeMe, video and voice over Internet Protocol, and a commercial “chat room” application was supported and allowed distributed tactical decision making based on a shared view of the situation.

Figure 6. Locations of Warfighters During the Distributed Collaboration in the ELB ACTD Demonstration

This type of capability will become more important in the future, as we encounter situations in which commander's intent, priorities, and rules of engagement will have to be interpreted and adapted to the situation in near real time. A full appreciation of the situation will demand an ability to consult with others in the chain of command or in adjacent commands so that all aspects of the alternative courses of action can be considered. Tactical decision aids will need to include capability for this type of distributed collaboration and consultation. They will have to be truly "network centric".

We also need to remember that knowledge and understanding of the situation required an ability to present information in a way that aligned it with the current operational context and integrated it to form recognizable patterns and relationships. The same is true for appreciation. We need to present the information in a manner that allows the user to view objectives, alternative courses of action, and potential enemy actions within the framework of the current situation.

The tactical decision support system needs to help users who are likely to be under considerable stress at the time. A human-system interface or a display that demands too much attention or that is intolerant of input-output errors will not be useful. A presentation that requires the user to integrate and correlate in his or her mind will be less useful than one which presents a clear and comprehensive picture of the important aspects of the situation and the implications of alternative actions.

The presentation should also allow the users to concentrate on the job at hand without having to keep track of uncertainties that are being managed. Automated assistance (software agents) can reside in the background to track those types of things and to cue or alert the user when necessary.

The ELB ACTD demonstration in 1999 showed the potential value of a tactical data network and decision support system operating across various levels of command. At each level, the users have a specific role to play in the decision and execution process, and they can structure their displays and human-system interfaces to correspond with their own needs. Software agents can provide cues and alerts for information that is being tracked, and drilldown is available when details are needed. However, for most of the time the users can focus on specific information associated with their jobs.

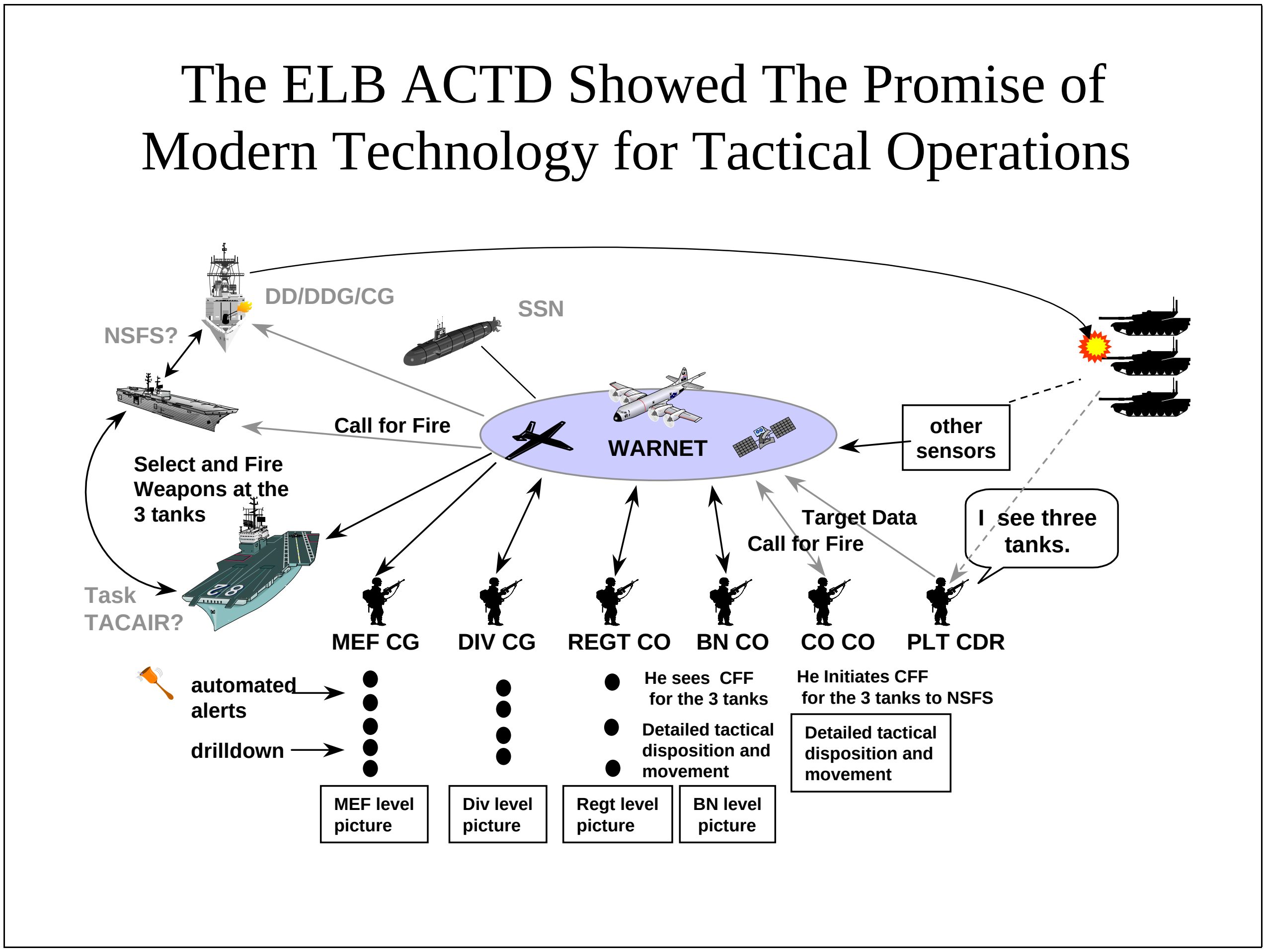
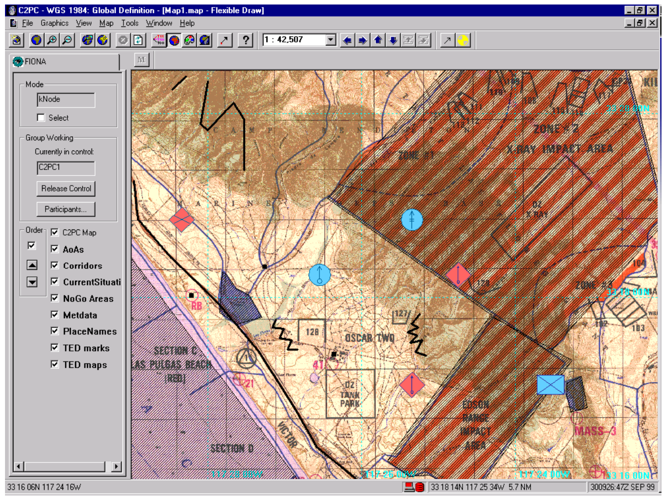


Figure 7. Tailored Views of the Situation to Adapt to the Needs of Each User

Figure 7 illustrates how each participant interacts with shared information to construct an appropriate picture of the battlespace and to reach a decision motivated by an observation of three enemy tanks. The decision at the lowest level is to report the observation. At one or two levels above this, the decision is made to call for fire. A decision for a specific indirect fire is made at a higher level in this example, and the overall direction of maneuvers and fires could be accomplished through a collaboration among several of the senior levels in the tactical chain of command.

Integrating the View of Situation, Objectives and Constraints Helps to Support the Decision



Logica's DOHP Overlay on a US Marine Corps C2PC Situation Display to Show NoGo Lines and Excluded Areas

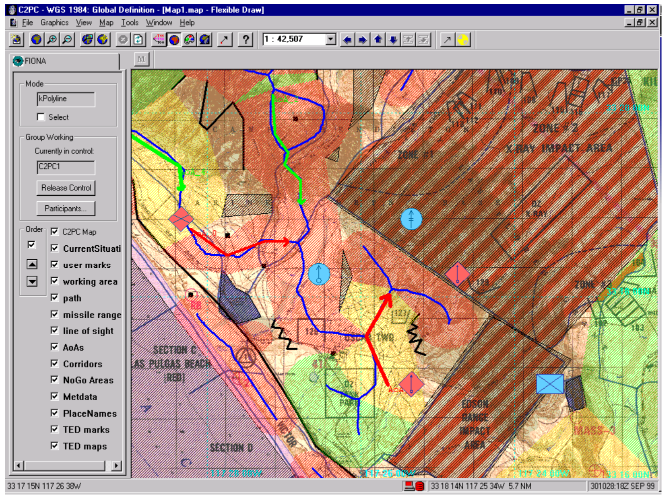
Figure 8. Integration of Other Decision Factors With Observed Situation Information

An appreciation of the situation and of the alternative courses of action is supported by displays that show how the constraints map onto the battlespace. Those constraints can be trafficability affected by the weather or terrain, or they could be due to rules of engagement or some other factors.

Figure 8 is a screen-capture from the Logica UK system discussed in the first lecture. It shows how an overlay of maneuver constraints can be superimposed on the map used to plan movements. The overlay itself can be a predefined template or it can include some elements that are calculated, such as weather-related trafficability or inter-visibility demands for covert movement. The Logica system provided software agents to construct and manage these overlays and provided the users with appreciation of where they could move.

The tactical decision aid can also advise users of potential courses of action for both themselves and enemy forces. The overlay shown in Figure 9 was provided in the Logica system to show where units of various sizes could maneuver. The software agent that Logica used was based on a standard algorithm for maneuvering robots in spaces with obstructions. Logica adapted this algorithm to provide reasoning for military organizations moving through the hilly terrain at Camp Pendleton, California. We see the go, no-go areas of the prior overlay, and we see the allowable maneuver corridors added to the overlay.

Implications of the Observed Information Can Be Inferred and Integrated in the Display



Logica's Software Agents Construct an Overlay That Shows Maneuver Corridors for Forces of Selected Sizes and Compositions

Figure 9. Addition of Inferred Knowledge Can Provide Further Enhancement to Military Appreciation

The addition of the maneuver corridors (lines added to the map in Figure 9) gives the user an appreciation for actions that the enemy may take as well as his or her own allowed actions.

The power of this technology is multiplied by orders of magnitude when we share the overlay via the tactical data network. Then we can consult and collaborate to come to a decision on how to move ourselves in concert with the other elements of the force. We also have a means to do real time adaptation of maneuvers and fires and to update plans to match the situation.

Planning and selection of a course of action is only one part of the control and direction of tactical forces. The tactical decision support systems must also provide an ability to monitor and manage execution as the battle unfolds.

The Office of Naval Research and the Naval Air Systems Command sponsor a program at the Space and Naval Warfare Systems Command (SPAWAR) Systems Center in San Diego, California (SSC SD) to develop and deploy new capabilities for real time targeting, retargeting, and execution management for tactical aircraft. The program is called "Real Time Execution Decision Support" (REDS). REDS provides a variety of software tools, displays, and interactive query capabilities to allow the users to designate targets, develop strike packages and mission plans, and direct execution, including real time mission monitoring and plan adjustment. Operational prototypes are being deployed with Navy carrier air wings to test and evaluate the technology. An example of a REDS display is shown in Figure 10.

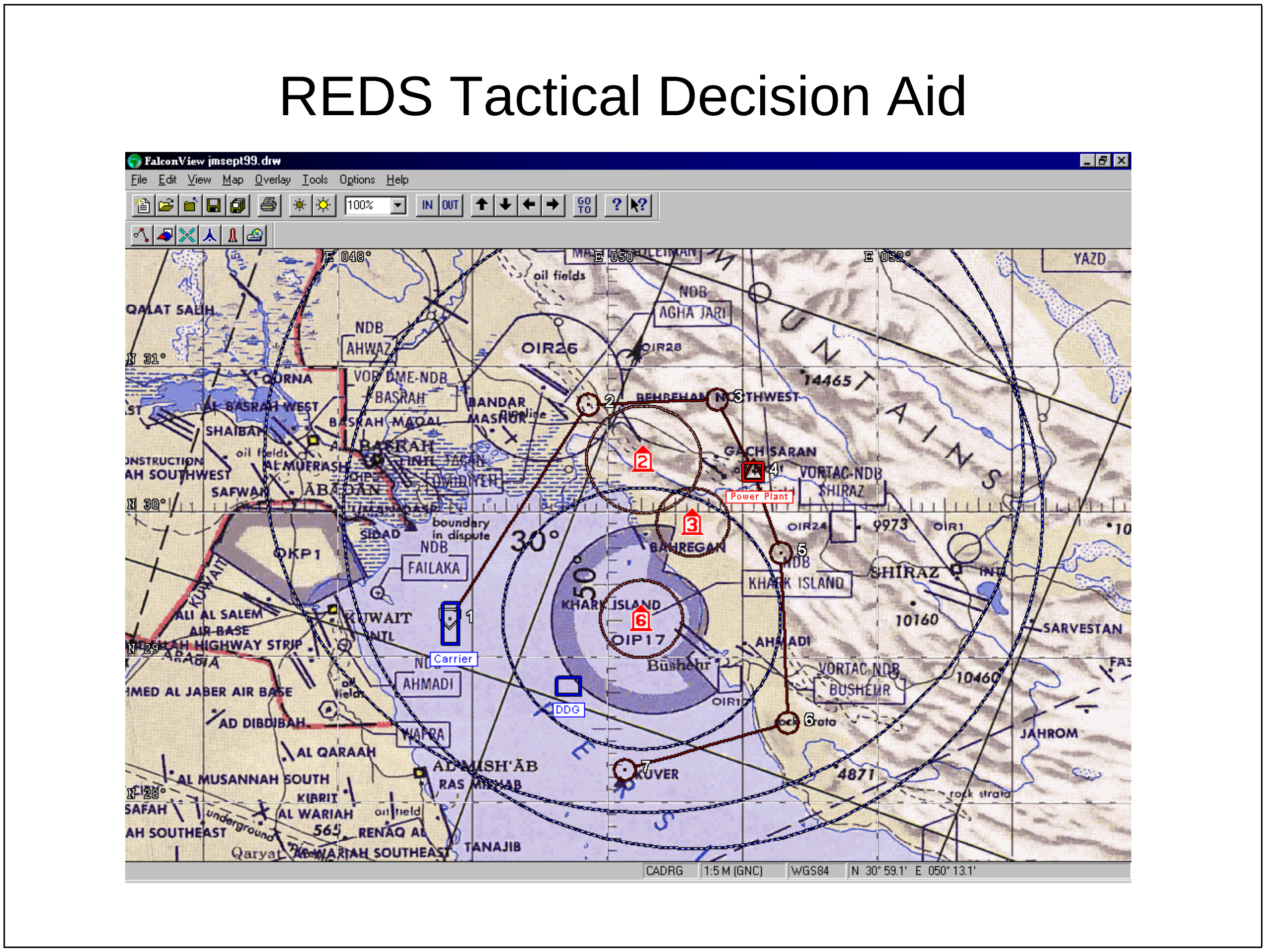


Figure 10. Decision Support for Real Time Planning, Replanning, and Monitoring of Execution

The REDS tactical decision aid provides a view of the battlespace that shows both friendly and threat capabilities related to the tactical air missions. These include radar coverage, missile envelopes, targets, and other features that the users need to plan missions and reach conclusions on best alternatives for engaging time critical targets in high threat environments. With such a tool, the mission planners can designate ingress and egress routes to avoid threats and can determine requirements for defense suppression, electronic warfare, and other support to the mission.

A need for tactical decision support does not end when the mission is planned, assigned, and launched. Ability to monitor progress and to adapt to unplanned contingencies is also needed.

The technique used in REDS is shown in Figure 11. It provides a display of the plan in terms of the desired sequence of actions and the specific times at which they occur. Those are the horizontal bars in the display. Each bar represents activities that are supposed to occur at specific times. The vertical line in the display is an indication of current time. It moves across the chart from left to right as time progresses. As it passes through the horizontal bars, they are assigned colors, from red to green, depending on whether the planned status at that time has actually been achieved.

This type of display is a very user-friendly, intuitive way for the tactical decision makers to view the entire set of missions and to identify where they are on-track or in trouble. This gives a very clear and quick comprehension, or appreciation, of the evolving situation with respect to the specific user's functional areas of responsibility.

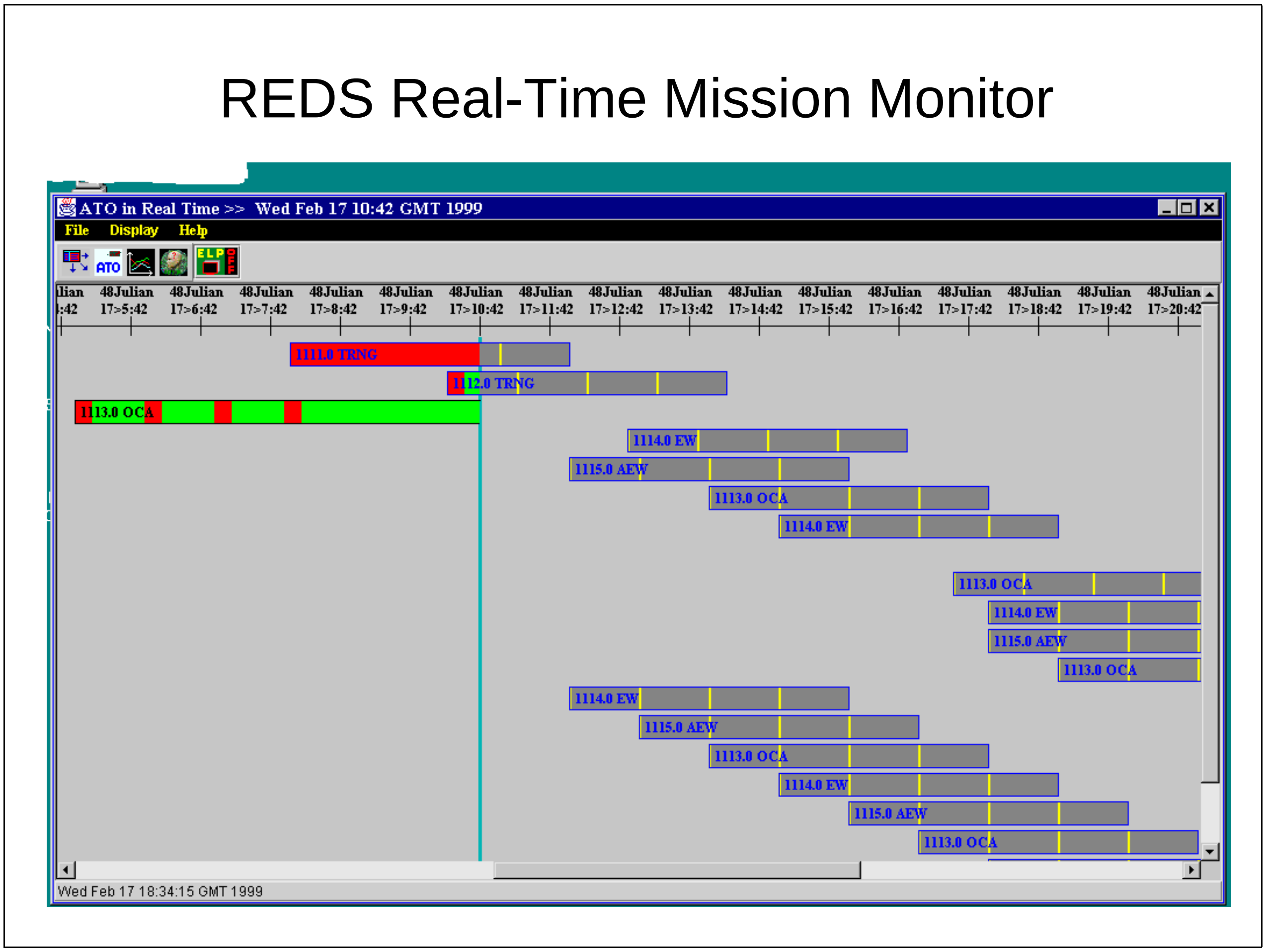


Figure 11. REDS Mission Monitoring Display

Other important factors in making a tactical decision are the specific empowerments and limitations of alternative actions specified by rules of engagement (ROE). ROE are developed at the highest levels of command and forwarded downward as text messages. At each level, the ROE can be expanded with further detailed guidance and interpretation, but most of this is still by text messages. As a result, the warfighters are burdened with manual processing of textual information and trying to keep track of the rules as they try to reach a decision.

ONR sponsors an effort at the SPAWAR Systems Center, San Diego (SSC SD) to automate the ROE development, dissemination, and application process. The ROE would still be developed and approved by commanders and their staffs, but the handling of this information would now be done much more efficiently and in a manner more suited to time critical decision making under stress. The ROE information would be entered into data bases in the tactical command and control systems, and the tactical situation data bases would have automated connections to the appropriate ROE information.

Figure 12 shows a hypothetical display of a tactical situation with the automated ROE augmentation. The formatted text box at the upper right hand corner of the screen tells the operator that ROE for attack have been satisfied. This is indicated very clearly as “ATTACK: YES”.

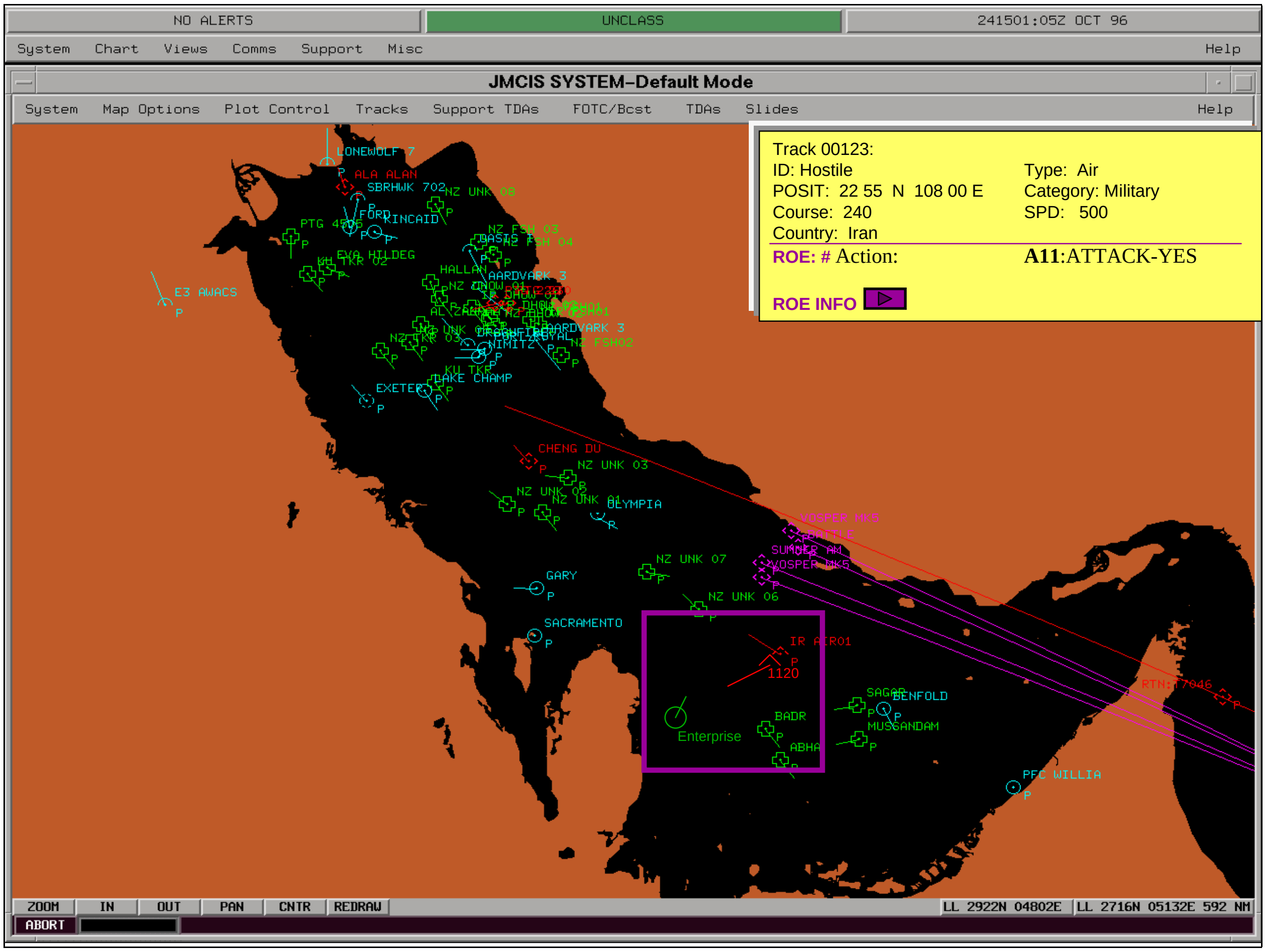


Figure 12. Rules of Engagement Integrated Into the Tactical Situation Display

If the operator needs to see the specific rationale for this decision that ROE have been satisfied, he or she can drilldown and request those details. Drilldown information is included in the display shown in Figure 13.

The ROE explanation box now shows the information that supported the conclusion that an attack was authorized under the current rules of engagement, based on specific observations. The conclusion that the ROE allow attack (ATTACK:YES) is based on two specific observables that satisfy that ROE. Those are noted as “CI: In No Fly Zone” and “C2: Target has previously attacked”.

The operator can conclude very quickly and unambiguously that the two criteria specified in the ROE have been satisfied and that the attack is permitted. This also provides a permanent record of the basis for the decision, which can be very useful for after-action evaluations, and also for legal considerations if such are necessary.

Remember that the appreciation of the situation usually leads to a judgmental decision with potentially lethal consequences. The ability to make such judgments is often improved if the decision maker can be sure that a clear and unambiguous basis exists for the judgment and that clear documentation of that basis will be preserved.

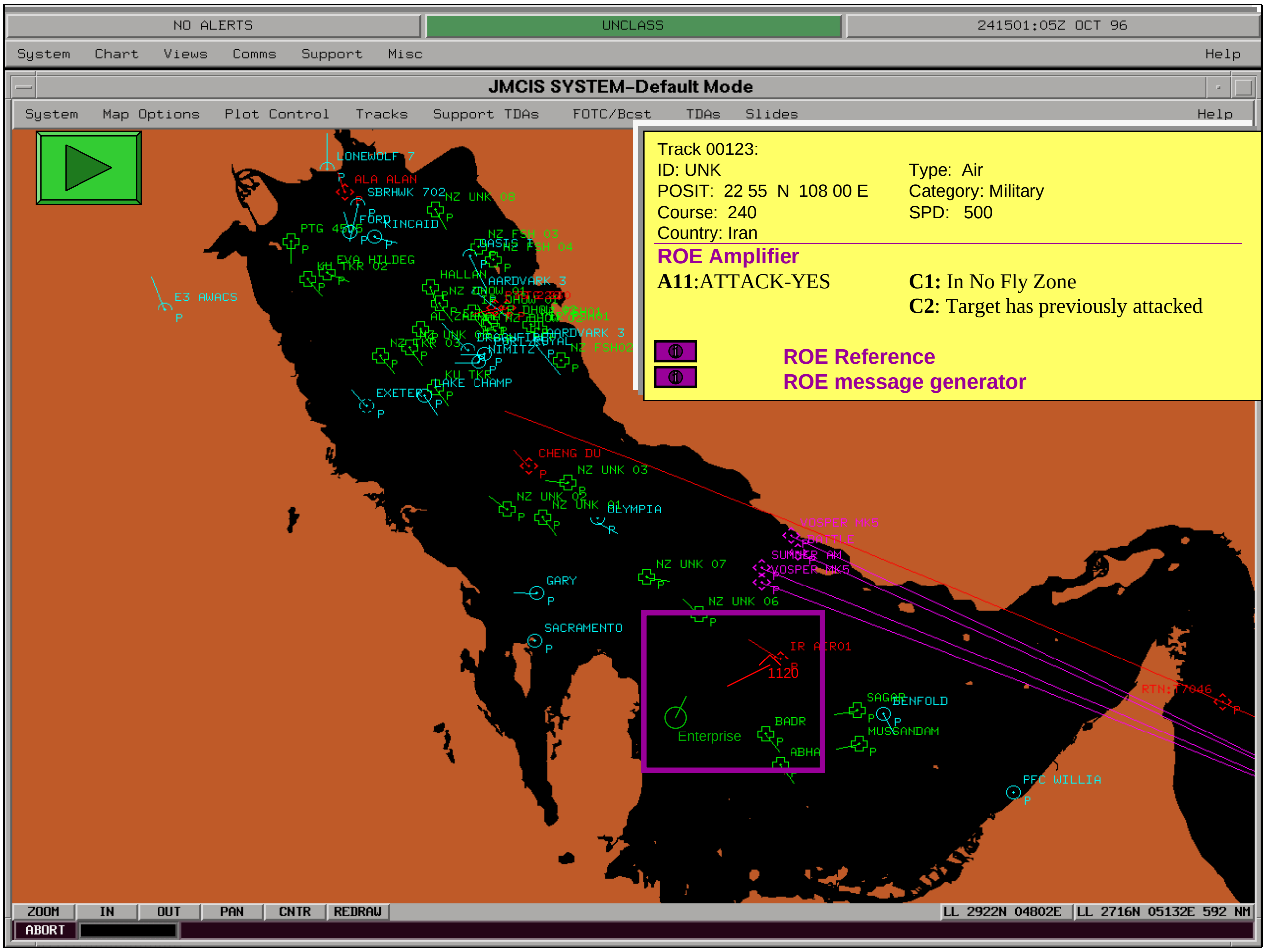


Figure 13. ROE Display With Additional Drilldown Details

Advanced information technologies such as those discussed here will cause major changes in command and control systems and processes. One of these changes is a shift from fully manual processes to a reliance on automation to support the human beings, and even toward fully automated processes.

Automation is most important for tactical combat systems and weapon control systems, where complexity and time demands make it difficult for human beings to be directly in the control loop. Even the act of flying an aircraft is sometimes beyond the capability of human beings. Modern tactical fighter and attack aircraft are often highly unstable platforms. This allows them to have very fast response, but it also makes them very difficult to fly by direct interaction of the pilot with flight control mechanisms. Consequently, a computer flies the aircraft, and the pilot exercises control of the computer, to provide specific objectives for it to meet. This is an example of a human-supervised automated process.

Tactical combat direction and command and control offer more opportunity for human beings to act within the decision loop. Here the demands of time compression and complexity are still large, but the human beings are able to cope with them as long as the automated systems provide them with timely and “user friendly” support. Systems such as the Logica tactical decision aid, REDS, and automated ROE are examples of important efforts to provide such support to users who are embedded in the tactical decision processes.

Figure 14 shows the wide variety of human-computer relationships that occur in command and control systems and processes.

The Relationship Between Humans and Machines Is Changing

- Manual Process
  - People Do the Work Using Pencil, Paper, Telephone, etc.
- Computer-Aided Manual Process
  - Humans Use the Technology to Do the Bookkeeping and the Mathematics and to Move the Information Among Themselves
- Automated Process
  - Computers Run the Show
- Human-Supervised Automated Process
  - Computers Run the Show, but Humans Can Monitor and Intervene Directly in the Process
- Human-in-the-Loop Process
  - The Human Is Inserted As a "Functional Module" Within the Automated Process
- "Mixed Initiative" Process
  - The Human and the Computer Do Interconnected Tasks

Figure 14. The Wide Spectrum of Human-Computer Relationships in Command and Control

Architecture, commonality, and interoperability are additional factors that need to be taken into account when building a command and control system. At the tactical level of command and control, we are often challenged by competing demands. On the one hand, we want to make use of common systems to the greatest extent possible to reduce burdens of training, operation, and maintenance. It also allows us to reduce total cost of ownership by using commercial-off-the-shelf (COTS) equipment rather than expensive, purpose-built military hardware and software. When requirements are not oriented on near real time control, general purpose systems are often appropriate.

Unfortunately, tactical systems can impose very stressing requirements for near real time response and software trustworthiness that often demand purpose-built technology. We do not rely on a COTS personal computer and general purpose software to generate fire control solutions within a second or less; and we do not want that COTS computer and software guiding the weapon in flight. For these functions, we generally embed purpose-built computing in the combat systems and weapon systems.

Tactical decision aids are at the unfortunate "seam" between technology based on general purpose and purpose-built computing. We will often find hybrid systems, where part of the process is based on COTS and part is purpose-built for the military task. This could change as the performance and trustworthiness of COTS improves, but we will have to live with the current situation until that time.

Figure 15 summarizes considerations of commonality versus purpose-built "stovepipe" systems.

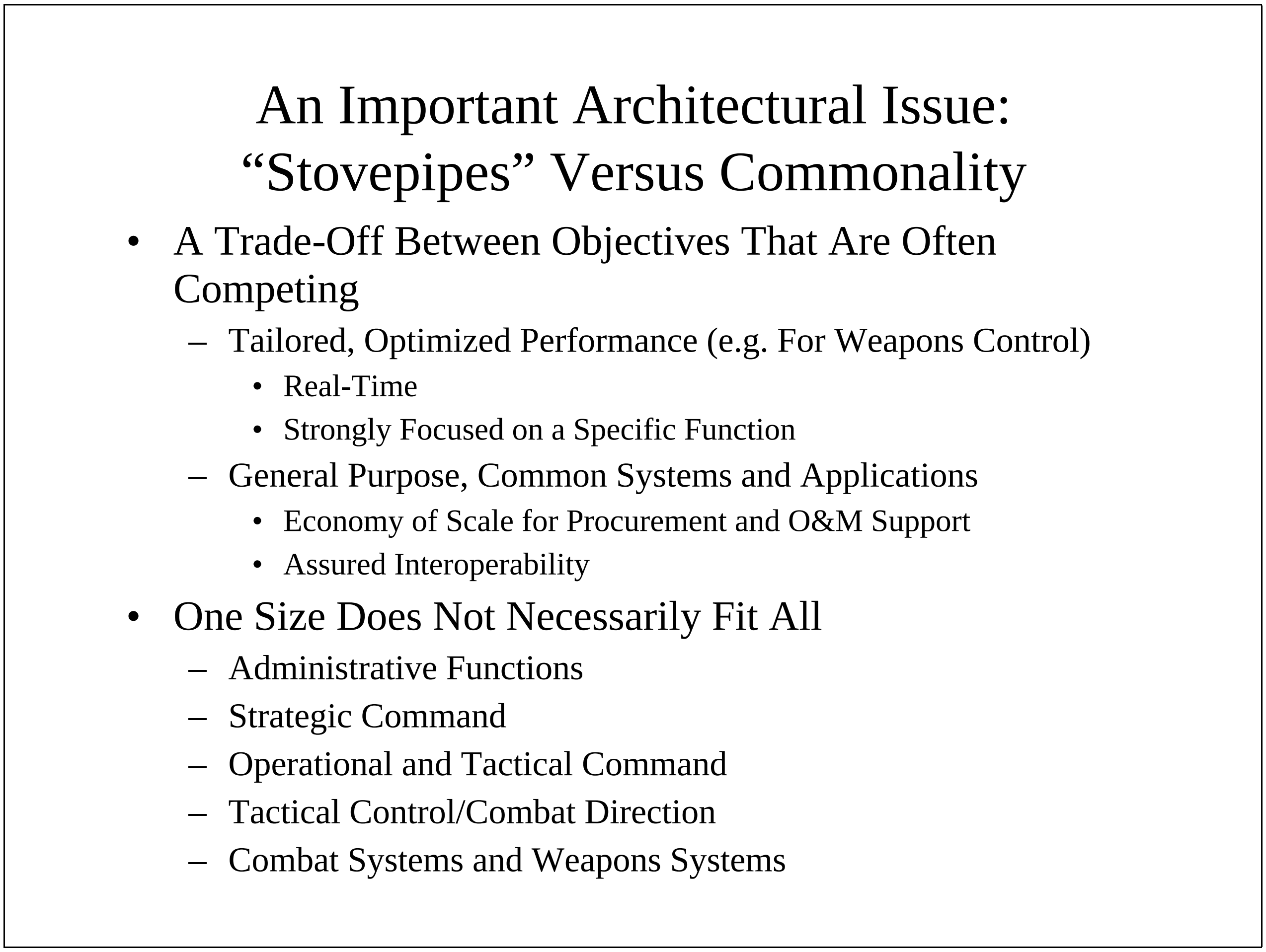


Figure 15. Considerations in Building for Commonality or Purpose-Built Functionality

No discussion of situational awareness and tactical decision aids would be complete without some reference to interoperability. This is especially true for coalition operations, where differences arise not only with the technologies but also with operational concepts, procedures, and language.

The first three "bullets" in Figure 16 are the interoperability areas that we are used to seeing. Once we achieve this level of interoperability, we can exchange data and process information. Our systems will work together at least to that extent.

The next two "bullets" address the parts of the process that enable knowledge, understanding, and appreciation. If we do not recognize semantic differences, we may misinterpret information and therefore make an error perception. If our responses to information are not common, we may make decisions that conflict with other decisions in the coalition force.

These last two "bullets" are the real challenge in coalition warfare. We know how to achieve interoperability up to the application level, and we even have some capabilities up to the semantic level, but we lack the fundamental tools to achieve the higher levels. This is a major focus area for current science and technology programs.

A Word About Interoperability What Does It Really Mean?

- Technical Interoperability
  - The Hardware and Software Can Operate Together
- Transaction Interoperability
  - Information Can Be Exchanged and Processed
  - Protocols Are Consistent Across the Systems
- Application Interoperability
  - The Applications Can Exchange Information
- Semantic Interoperability
  - Language and Meaning Are Commonly Understood
- Response Interoperability
  - The Expected Responses to Information Are Understood by All
  - e.g. We’ve Heard the Joke About: “Secure the Building”

Figure 16. Interoperability

In summary, the movement toward “information-leveraged” warfare, whereby the warfighters achieve greater effectiveness through better use of information, has both positive and negative aspects.

We saw in the first lecture that the “fog of war” may be penetrated to some degree, but it will still exist. We also saw that the technology that helped penetrate the “fog” presented us with potential overload, the “glare of war”.

In this second lecture we saw that a major challenge in modern warfare is to be able to respond very quickly to complex situations and to reach a military appreciation and a decision based on our appreciation of the situation. This caused us to be concerned with making judgments based on imprecise information, where lack of credibility and confidence can be impediments to decision making. We saw that some form of “partnership” between the human beings and the technology will be required as we move more and more toward the real time tactical functions or toward the massive data base environments of the higher level operational and strategic commands.

These challenges provide a rich context for current research and development for situational awareness and understanding and tactical decision aids.

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Mission Management and Crew Assistance for Military Aircraft – Cognitive Concepts and Prototype Evaluation –

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1 SUMMARY

This paper describes an approach to cognitive and co-operative operator assistance in the field of tactical flight mission management. A framework for a generic functional concept is derived from general considerations of human performance and cognitive engineering. A system built according to these human-centred design principles will be able to keep up with the change of situation parameters, in order to provide situational adapted operator assistance. Such a *Cognitive Assistant System* (e.g. Onken & Walsdorf, 2000) represents an approach to ensure the highest degree possible of situation awareness of the flight deck crew as well as a satisfactory workload level.

This generic approach to mission management and crew assistance for military aircraft has been realised in different application domains such as military transport and air-to-ground attack. Even applications in the domain of unmanned aerial vehicles (UAV) (Stütz et al., 2001) are in reach. This paper mainly covers two state-of-the-art research and development activities: the *Crew Assistant Military Aircraft* (e.g. Schulte & Stütz, 1998; Frey et al., 1999; Stütz & Schulte, 2000) is a functional prototype for the air transport application and the *Tactical Mission Management System* (e.g. Schulte et al., 1999; Schulte et al., 2001/a&b) as an experimental solution for air-to-ground attack aircraft. The paper gives details on the prototype development and the experimental evaluation.

2 INTRODUCTION

Performing military combat missions in an uncertain dynamic tactical environment, presents a potentially intolerable workload for the crew. Therefore, several research and development activities are conducted in order to automate flight crews' tasks. Figure 1 illustrates the expected benefit of an increase of complexity of conventional automation as opposed to a so-called *cognitive automation* approach (e.g. Onken & Walsdorf, 2000; Putzer & Onken, 2001). Investigations of modern aircraft cockpits show that a further increase in use of conventional automation will not necessary result in increased productivity. Automation itself became a complex element within the already complex environment of the cockpit. In some cases conventional automation has even become the key-factor for decreased safety (e.g. due to 'mode confusion'). (e.g. Wiener & Nagel, 1988) The reason for this seems to be found in the unpredictability of the machine's behaviour due to inconsistencies between the machine function and the pilot's mental model of it.

Consequently, Billings (1991 & 1997) stated his well known principles of *human-centred automation* i.e.:

- The pilot bears the responsibility for safety of flight.
- Pilots must remain in command of their flights.

And as corollaries:

- The pilot must be actively involved.
- The pilot must be adequately informed.
- The operator must be able to monitor the automation assisting them.

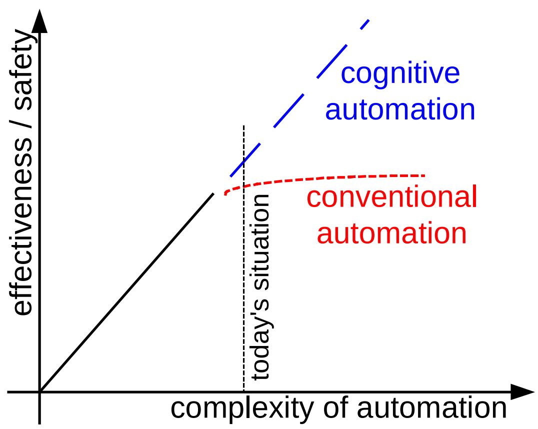


Figure 1: Expected benefit of conventional and cognitive automation

Paper presented at the RTO SCI Lecture Series on "Tactical Decision Aids and Situational Awareness", held in Amsterdam, The Netherlands, 1-2 November 2001; Sofia, Bulgaria, 8-9 November 2001; Madrid, Spain, 12-13 November 2001; Maryland, United States, 19-20 November 2001, and published in RTO-EN-019.

- The automated systems must be therefore predictable.
- The automated systems must also monitor the human operator.
- Every intelligent system element must know the intent of other intelligent system elements.

These principles imply the co-operative approach, establishing the automation as a team player within the flight-deck crew. But, how can this practically be accomplished? Onken (1994) formulates his basic requirements concerning human-machine interactions in combat aircraft as follows (cited from Onken & Walsdorf, 2000):

(1) It must be ensured the representation of the full picture of the flight situation, including that the attention of the cockpit crew is guided towards the objectively most urgent task or sub-task as demanded in that situation.
(2) A situation with overcharge of the cockpit crew might come up even when situation awareness has been achieved by the pilot crew. In this case the assistant system has to transfer the situation into a normal one which can be handled by the crew in a normal manner.

The basic requirement (1) addresses the system performance needed to most effectively ensure the pilots' situation awareness. The basic requirement (2) is formulated to avoid pilots' overcharge, in particular as to planning, decision-making, and plan execution tasks.

The actual automation functions required to provide intelligible interaction and efficient use of such a cognitive assistant system are derived from a concept taking into consideration the process of human information processing, the *cognitive process* (as described in the following chapter). The approach aims at the provision of crew assistant functions which focus upon the interpretation and diagnosis of the situation and the monitoring and if necessary the retrieval of the integrity of superior goals such as safety, combat survival and mission accomplishment (Schulte & Stütz, 2000). In order to realise this approach, a way had to be found how to deal with human goal knowledge in machine systems. Today's cockpit avionics completely neglect this kind of information. Of course, the treatment of goals is implicit (e.g. GCAS is designed to avoid ground collision per definition). But, goals, goal violations and the possible interference of different goal domains (e.g. combat survival vs. mission accomplishment) are not yet processed explicitly. In most cases conventional automation is used in more or less separated systems. Coupling of application domains (e.g. ground collision and threat exposure) has to be performed by the human operator on his own. Cognitive systems promise the exploitation of synergetic resources within the co-operation of machine system and human operator. (See Figure 2.)

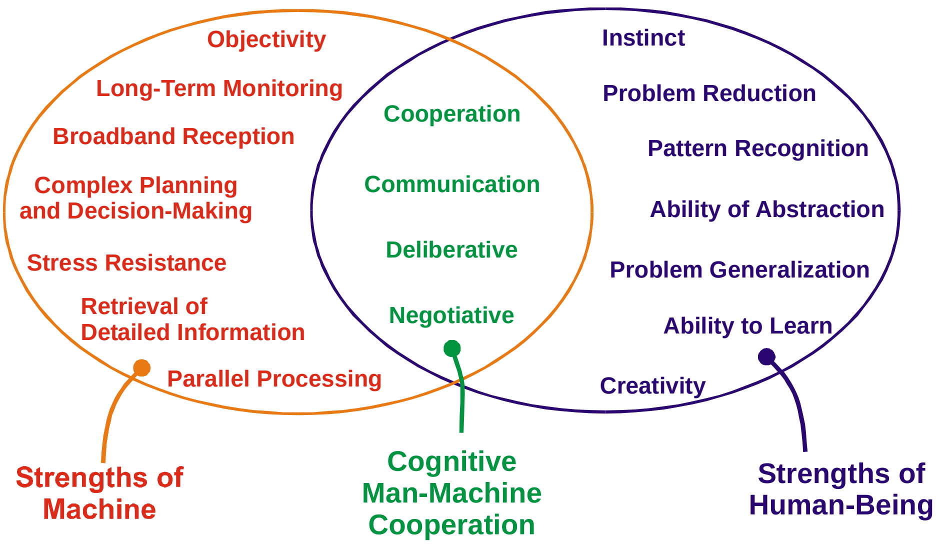


Figure 2: Synergetic resources to be exploited through man-machine co-operation

The next chapter deals with the refinement of such a cognitive automation concept on the basis of the consideration of the human knowledge processing scheme. A generic functional framework will be derived. The following chapter provides the results of two research and development programmes being based upon these concepts.

3 COGNITIVE CONCEPTS

In the introduction the issue of changing from a conventional automation philosophy towards a more advanced and promising concept in terms of safety and productivity has been just scratched on the surface. The following sub-sections are meant to discuss the cognitive design philosophy in a more systematically manner.

The first issue to be considered is the paradigm of migration from conventional automation towards a co-operative architecture. The work process levels in order to classify the cockpit tasks are defined having Rasmussen's (1983) human performance levels in mind. Co-operative work-share between human and machine, yet, demands advanced capabilities on the machine side.

In a next step the human problem-solving strategy and the cognitive process are considered in order to form a framework for the definition of such machine functions dedicated to the establishing of a close-partner work relationship between the automation and the human operator. Again, a model of the human problem solving strategy based upon Rasmussen's work (1983 & 1986) is used to identify current shortfalls in automation.

Finally, the approach of goal handling within the machine system is treated in order to enable the machine to interact on a knowledge based cognitive level. A model of superior goals and the deduction of resulting tasks is given.

3.1 Co-operative automation

The variety of tasks to be performed by the pilot during a tactical flight mission result in a workload on all work process levels (see Figure 3), ranging from skill-based manipulatory control (bottom/yellow) through rule-based system interaction (middle/green) up to general knowledge-based problem solving tasks (top/blue). Conventional automation traditionally focuses on relieving the crews from exhausting routine actions, thereby being granted full autonomy in certain well defined areas (Figure 3, left). Expanding this strategy of automation into task domains primarily subjected to rule- and knowledge-based crew action, leads to severe problems in the area of man-machine interaction (Figure 3, middle). Significant for this kind of development are very complex avionics structures and functions taking over full autonomy for comprehensive parts of the flight, while reducing the pilot to a mere solver of abnormal situations (Hollnagel, 1995; Billings, 1997). Therefore, new progressive methods are demanded when it comes to expand automation into all aspects of flight and mission management. The most promising way to proceed is the concept of an automated system acting in a co-operative relation rather than separating the crew from the basic aircraft systems (Figure 3, right). Being well aware of the complex task to perform, the crew interprets the output of the automation system as the recommendation of an additional electronic crewmember. The decision-making to accept or reject the machine's advice is allocated to the crew. Proceeding this way, the crew is kept continuously in the decision loop, as according to Billings' principles, and is able to employ the full strength of human performance. At the same time the crew takes advantage of the particular strengths and abilities of the system.

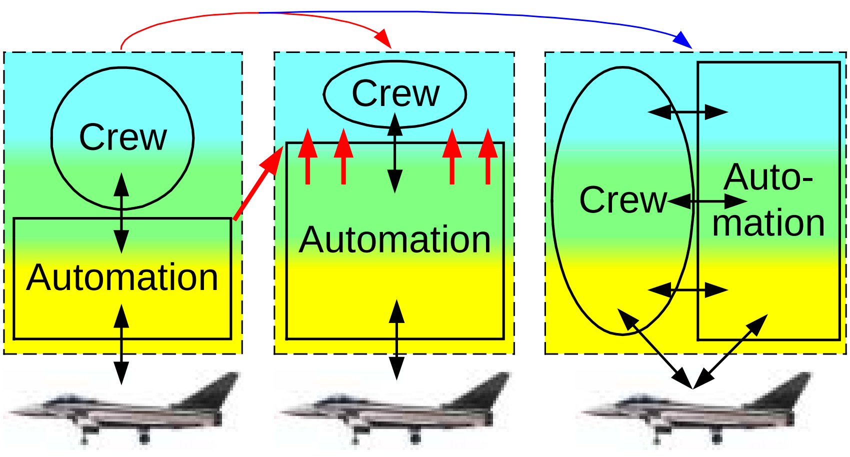


Figure 3: Conventional / co-operative automation

Establishing the postulated co-operative task allocation within a close-partner work relationship between the human operator and the machine requires to qualify the automated system to be an equal and competent team player, as one would expect from a human counterpart. The next section yields a closer look at human performance models in task situations to be used as a paradigm for a technical system's human-like behaviour.

3.2 Human problem-solving strategy and the cognitive process

Considering the automated functions within today's cockpit avionics and flight guidance systems against the background of Rasmussen's model of the human knowledge processing scheme (see Figure 4) shortcomings in conventional automation design can be easily identified (Onken & Walsdorf, 2000). It covers only about the half of what has been considered the spectrum of human cognitive functions. This situation calls for action in the fields of a profound situation recognition and identification as well as the goal-driven decision-making. This scope of duties is in compliance with Onken's basic requirements as cited above. Cognitive automation will cover the whole process of building an internal comprehensive representation of the relevant parts of the external world (i.e. the picture of the situation), a type of activity which has been mostly left up to the human operator, so far. The so-gained situation picture will be the basis for the crucial goal-driven decision-making process (Putzer & Onken, 2001).

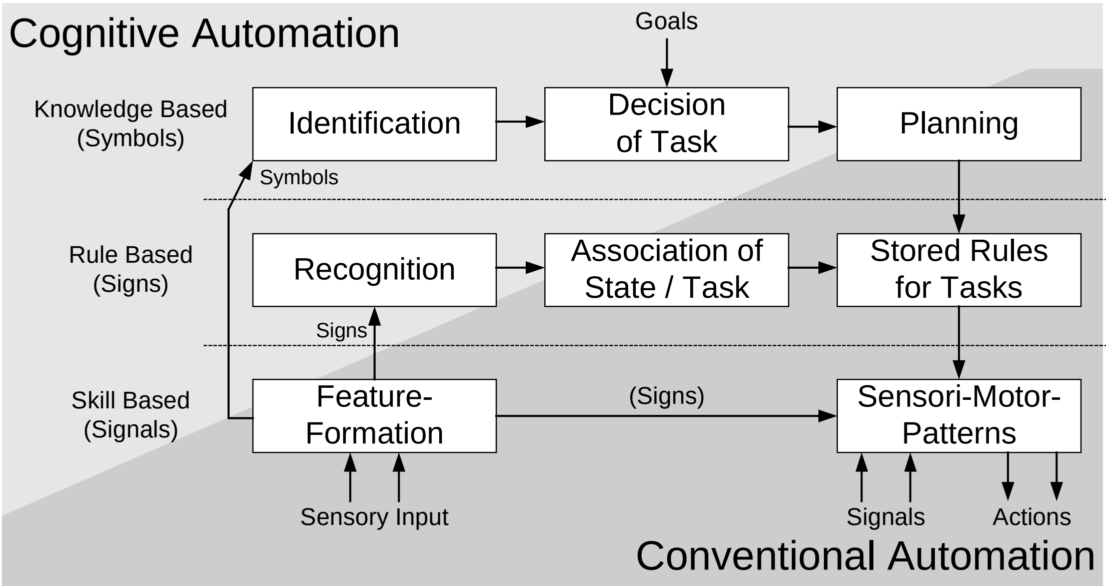


Figure 4: Scope of cognitive and conventional automation within the Rasmussen scheme (1983)

Besides an effective means of communication, a prerequisite to establish this partnership relation between man and machine is the implementation of transparent functional behaviour within the automation system. In order to make the machine output easy to comprehend and evaluate, and to establish a close-partner work relationship, both crew and machine have to reason from the same principles. Thus, the analogue problem-solving strategies and mechanisms have to be implemented in the automated system in a similar way to that which can be found in the human counterpart. This concept is the core element of cognitive automation.

Figure 5 yields a modified view on the elementary steps of human problem solving behaviour, which tries to reflect the aspects of condensation of information on higher processing levels and the closed-loop system properties of the human being feeding back to his environment. This behaviour model can be easily transferred into a design of machine functions (Schulte & Stütz, 2000).

On the lowest level a state-oriented acquisition of environmental signals is conducted and direct manipulatory output is generated. Problems demanding a certain amount of data abstraction and knowledge transfer typically cannot be solved on this level. Therefore, further data interpretation is necessary, taking into account superior context knowledge. A task-related aggregation and fusion of information can be derived as a result. On the structure-oriented level the data so-gained is further processed using additional rule and knowledge bases in order to reach a more profound problem diagnosis and a spectrum of possible solutions. Again, back on the context-level, a decision on how to proceed is found by the use of planning and forward-simulation results. Then, the derived solution is passed to the state-level for execution, thus ensuring successful problem solving under consideration of all relevant circumstances and all available information.

Simple automation implementations within clearly-cut task domains such as auto-pilot or flight director systems usually can be seen as immediate instantiations of the processing steps on the state-level, which are directly connected through functional relations. Autonomous planning functions are state-of-the-art in today's

Flight Management Systems. Assisting the crew also on the higher levels of their problem solving tasks, some abstract and therefore more versatile task knowledge has to be made available to the machine.

The cyclic character of the knowledge-based information processing procedure within the human being as well as implemented in a machine system has been brought to the point by the research group around Onken (e.g. Walsdorf et al., 1999; Onken & Walsdorf, 2000 and many other publications). Derived from the recognition-act cycle they construct a comprehensive model of the cognitive process or cognitive loop (see Figure 6). The cognitive loop comprises six cognitive sub-processes which will be run through continuously. The cognitive sub-processes are referred to as:

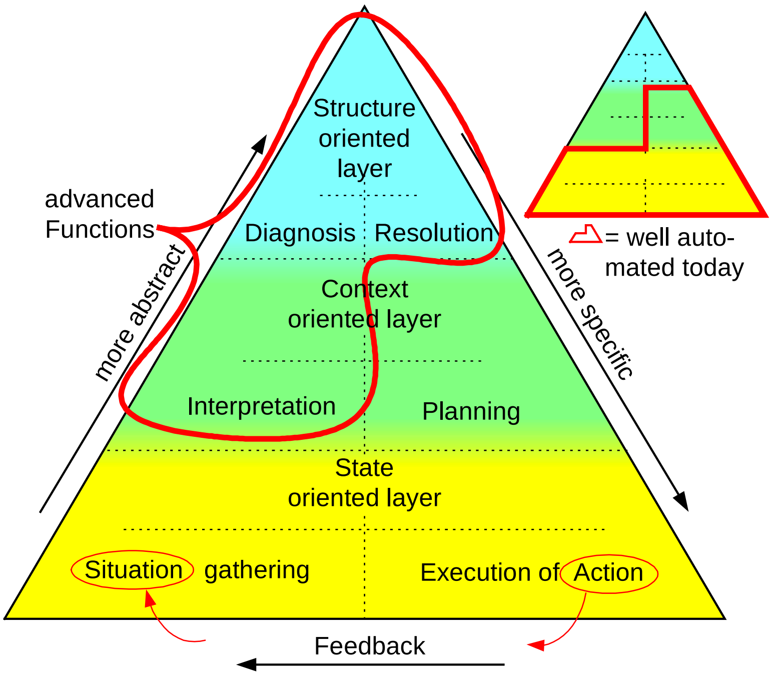


Figure 5: Human cognitive problem solving behaviour

(1) data acquisition from the external world,
(2) situation interpretation,
(3) goal activation (i.e. situation diagnosis),
(4) planning and decision making,
(5) scheduling of the tasks to be performed and
(6) control and execution of the derived actions.

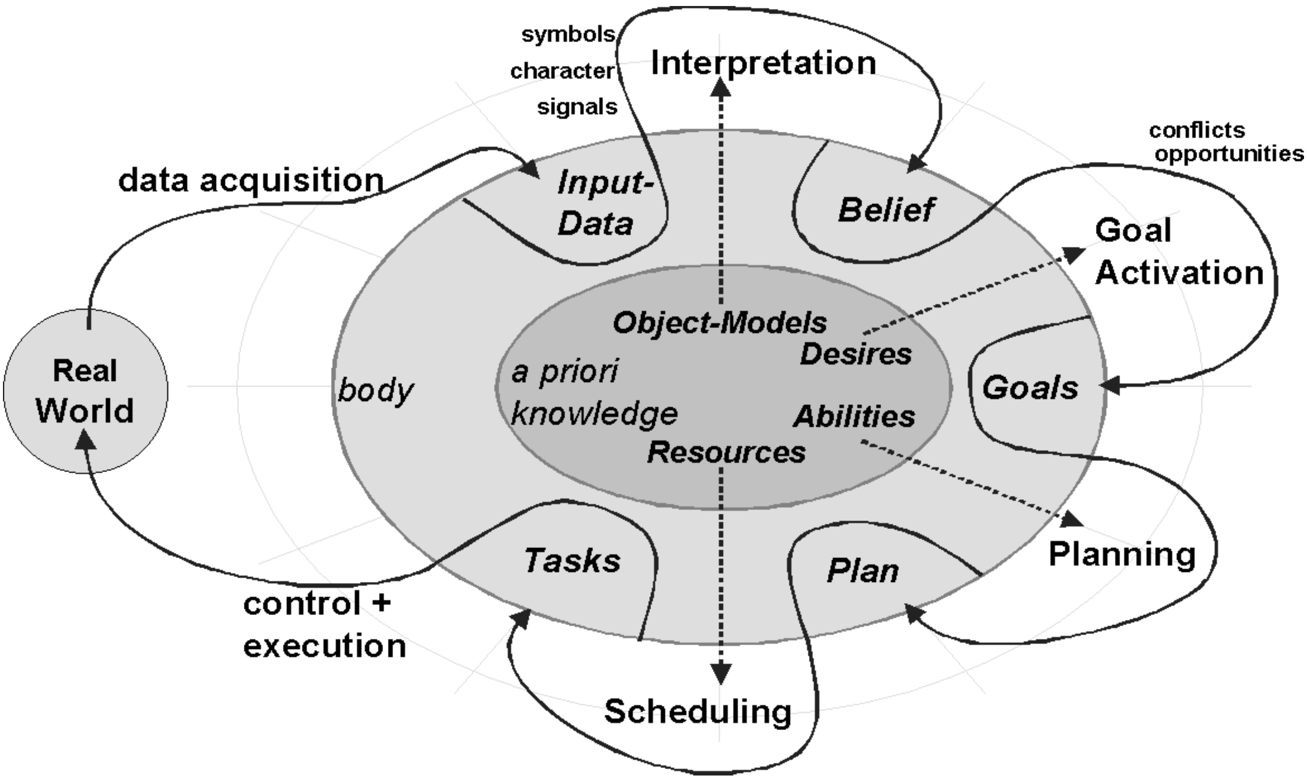


Figure 6: Overview of cognitive process as a model for required machine functions (Putzer & Onken, 2001)

Besides the sub-processes a main building block of the cognitive loop is the knowledge-trunk. It comprises

- static background (a priori) knowledge relevant for the application domain, and
- dynamic situation (a posteriori) knowledge generated as an output of the cognitive sub-processes (i.e. *mental model / cognitive yield*).

The combination of both as well as the relations amongst the diverse knowledge objects constitute the basis for the knowledge-based situation interpretation, diagnosis, decision-making and scheduling processes. Onken and Walsdorf (2000) suggest a formal treatment of the situation knowledge. Putzer & Onken (2001) describe the cognitive sub-processes (= *Transformators*) and their strict object-oriented implementation in more detail.

3.3 Goal and task model

As the structure of functions stated above makes obvious, a machine-immanent representation and processing of goals and tasks is compelling, thus establishing a common ground of understanding between the avionics system and the crew. Reasoning from first principles, the machine system is capable of inferring the same solutions a human pilot is most likely to reach in this situation. This goal model considers the principal kinds of pilot motivation such as flight safety, combat survival and mission accomplishment (see Figure 7) (Schulte et al., 1999; Schulte & Stütz, 2000).

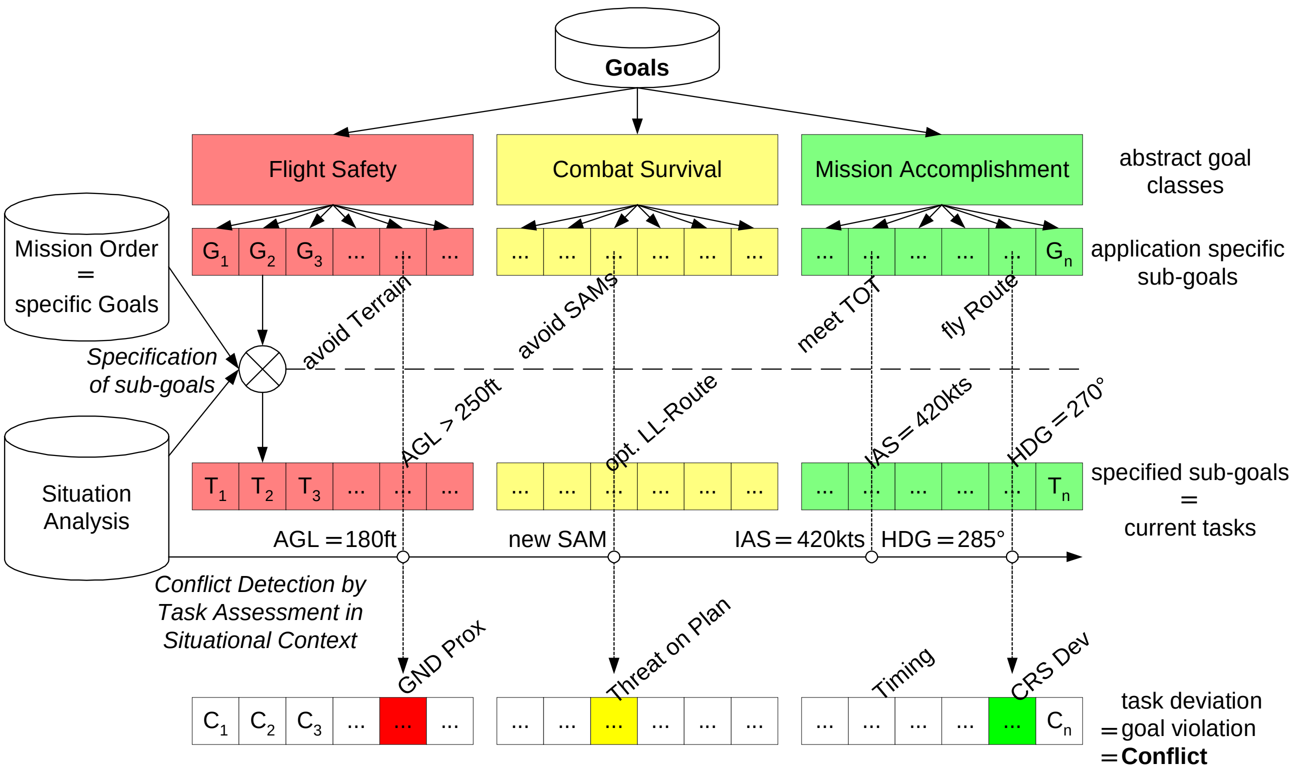


Figure 7: Model of goals and tasks for conflict detection

The primary aim of the introduction of the goal/task model is the detection and prioritisation of conflicts in the mission progress. A conflict is defined as the violation of a goal. Starting from the abstract goal classes, application-specific sub-goals are derived (e.g. meet a given time-over-target, TOT). The parameterisation of the sub-goals is performed using the mission order and the current situation. This might include the application of scheduled values or tolerances and even the de-activation of single sub-goals according to the current flight phase (e.g. goal ‘meet TOT’ is no longer relevant in the flight phase Ergress). For conflict detection the specified sub-goals (i.e. current tasks) are compared with the actual situational parameters. In the case of an intolerable deviation a conflict is detected and can be passed on for further processing.

This approach heavily relies on its capability to analyse all situational elements and their influence on the given goal structure. Several sub-functions using expert knowledge are necessary to perform the needed interpretation of flight progress, environmental, tactical and aircraft data. Only when this overall situational picture is available to the machine system it is possible to determine and prioritise goal violations reliable by the centralised goal conflict analysis.

3.4 Determination of current pilot tasks

Defining the relevant goal structure for finding conflicts and appropriate conflict solutions is greatly influenced by the aircraft's current state in flight progress. Therefore, the capability of autonomous flight phase recognition is vital to the system. This includes the determination of the pilot's tasks.

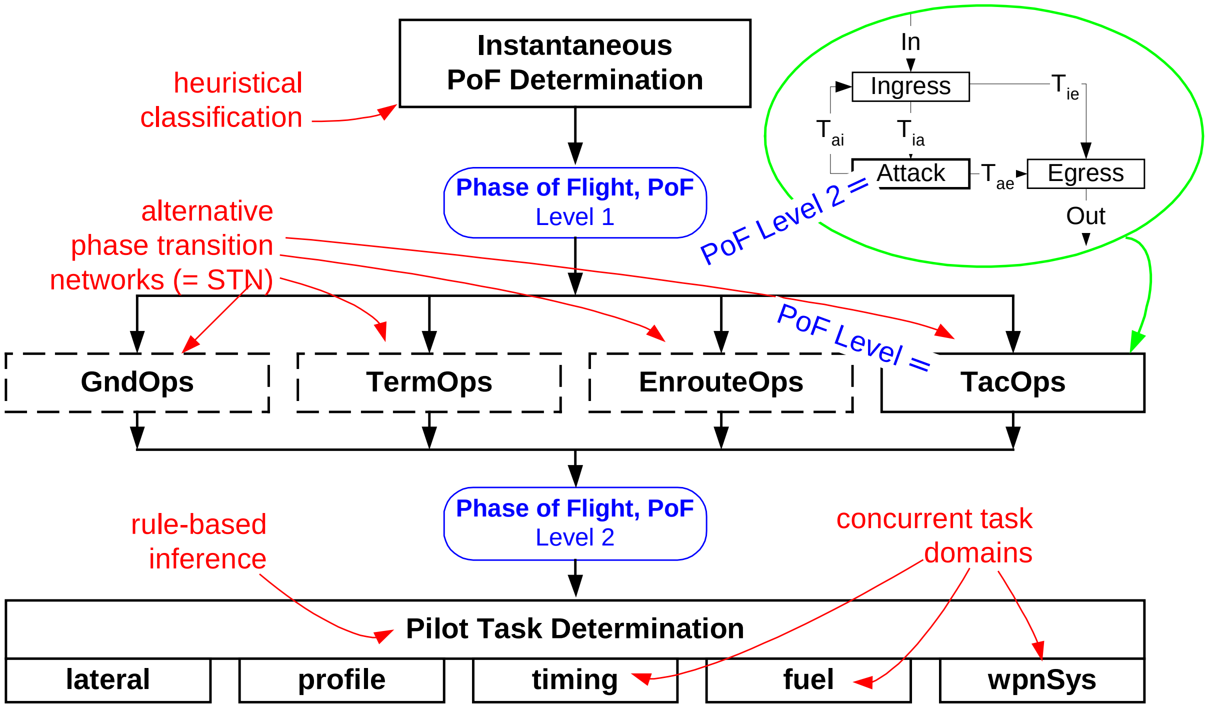


Figure 8: Phase of flight and pilot tasks determination

Figure 8 shows the architecture of the continuous phase of flight (PoF) and pilot tasks determination. The cross in Figure 7 marks about the place where this sub-system has to be inserted into the goal – task model. The starting-point of the algorithm is an instantaneous top-level phase of flight determination based upon a heuristical classification approach. The PoF Level 1 triggers the activation of one of the phase transition networks, each of which represented by a State Transition Network (STN). The inset in Figure 8 gives an idea of such a network. The output of the active network is the refinement of the flight phase. The PoF Level 2 controls the rule-based inference mechanisms in concurrent task domains for the pilot's expected tasks determination. Thereby, the required sub-goal specifications can be derived in order to determine the current tasks for monitoring by the system.

4 PROTOTYPE EVALUATION

After having formulated the cognitive system approach in the field of crew assistance and tactical mission management, this chapter deals with the description of two different experimental systems: The Crew Assistant Military Aircraft (CAMA) and the Tactical Mission Management System (TMM). Both prototypes were developed according to the described design principles of cognitive automation.

4.1 Crew Assistant for Military Transport Aircraft

The *Crew Assistant Military Aircraft* (CAMA) provides an example of how to assist military cockpit crews during transport missions. CAMA is a knowledge-based cognitive assistant system under development in close co-operation between the partners ESG, the University of the German Armed Forces, the German

Aerospace Research Establishment (DLR), and EADS Military Aircraft since 1993. CAMA is the latest development within the Cockpit ASsistant SYstems family derived from CASSY (e.g. Prévôt, et al., 1995).

4.1.1 Prototype implementation

This sub-section will give a brief insight into the functional modules of CAMA. Figure 9 shows the functional structure of CAMA. It basically follows the generic structure of the cognitive sub-processes as stated before.

In order to ensure situation awareness for the machine system, all information produced by the modules is assembled in a *Central Situation Representation (CSR)* and this way provides a complete dynamic database of the current situation. This can be seen as an analogue to the pilot's own mental representation of the actual situation. Static databases contain information such as navigational, terrain and feature data. The CSR forms the body of the cognitive process as shown in Figure 6.

Dynamic external data such as aircraft sensory data, air traffic control and C² instructions as well as environmental information are gathered via an external communication interface. This part represents the cognitive sub-process (1) of data acquisition from the external world.

Various modules provide crucial information on health status of aircraft systems (SI), environmental aspects (EI), and the flight progress. The *Tactical Situation Interpreter (TSI)* calculates the local threat distribution along the mission plan. In this way CAMA is able to perform conflict detection with respect to local changes in the tactical situation. The modules *Pilot Behaviour Interpreter (PBI)* as well as *Pilot Intent and Error Recognition (PIER)* serve mainly for the monitoring of pilot behaviour, which is described in more detail in (Stütz & Onken, 2001). These modules establish the cognitive sub-process (2) of situation interpretation within the cognitive loop.

On the basis of situation knowledge, possible conflicts ahead can be identified (e.g. threats, weather) by the *Flight Situation and Threat Interpreter (FTI)*. Here the impact on the current flight is assessed, conflicts are detected, and resolution activities are initiated. The module FTI is the implementation of the cognitive sub-process (3) of goal activation.

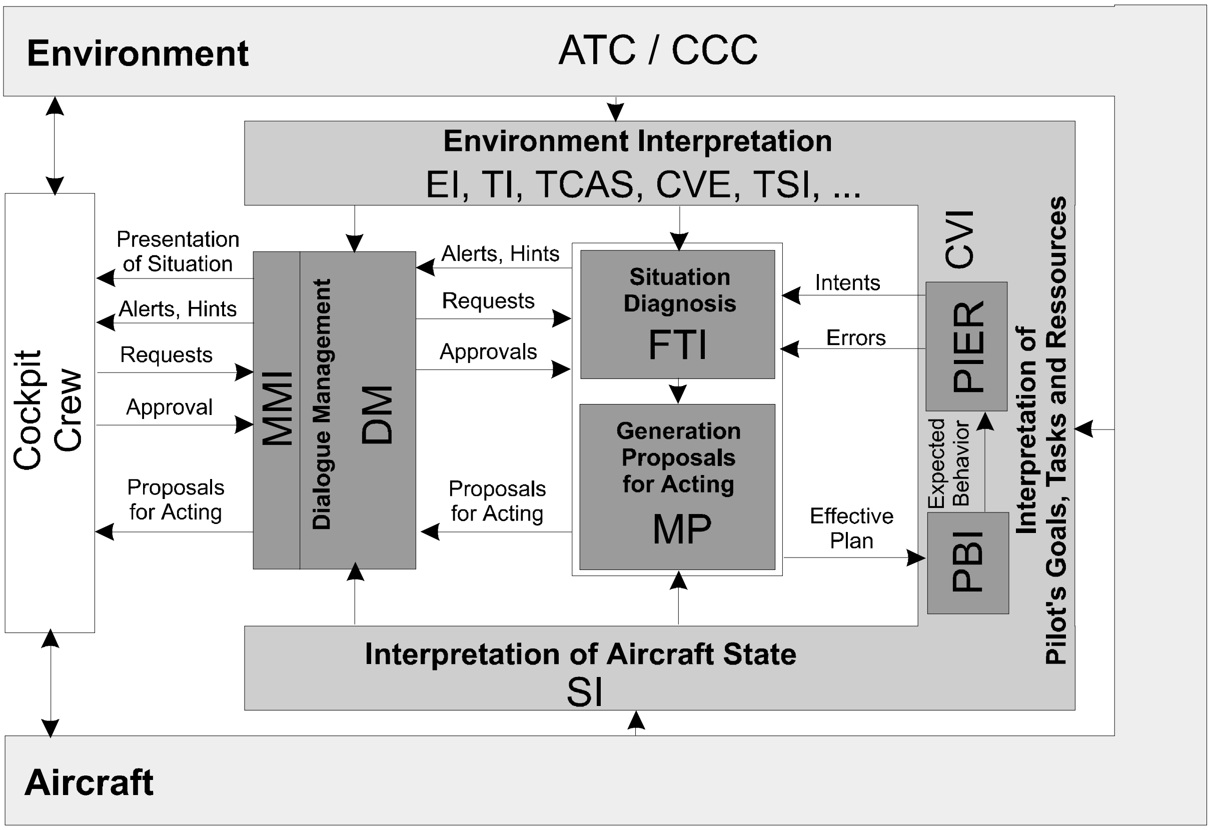


Figure 9: Functional Structure of the Crew Assistant Military Aircraft

The *Misson Planner (MP)* generates a complete 3D/4D mission plan either on demand by the crew or autonomously, where the crew does not have the resources to interact. The mission plan consists of both IFR- and low-level flight segments. The module MP can be seen as the representation of the cognitive sub-process (4) of planning and decision making.

The interface between CAMA and the crew is controlled by the module *Dialogue Manager (DM)*. Speech output is being used for focusing the pilot's attention on the important aspects. More complex information is transmitted using graphical displays. Information input is realised utilising speech recognition to a large extent (Flemisch & Onken, 1998). The DM-related functions cover comprehensive parts of the cognitive sub-processes (1) data acquisition from the cockpit crew as part of the machine-external world and (6) control and execution of the derived actions with respect to the pilots.

After successful module integration, CAMA was tested thoroughly in two flight simulator campaigns in 1997/98 (Schulte & Stütz, 1998). The results of these investigations led to further consolidation of the implemented functions.

4.1.2 Experimental design

In spring and fall 2000 CAMA was integrated in the experimental cockpit of ATTAS, the *Advanced Technology Testing Aircraft System* of the DLR, based on a VFW 614 aircraft, in order to be evaluated in flight trials. The following paragraphs give an overview over the experimental design prepared for the two flight test campaigns. (See also Stütz & Schulte, 2000 for the results of the first campaign.)

Apparatus, scenario and tasks

The experimental cockpit of ATTAS enables the investigation of advanced avionics functions under real flight conditions, thereby providing full access to the on board fly-by-wire system and navigational means. Standard interfaces to the aircraft are given through a side-stick, a flight control unit (FCU), a radio management unit (RMU) as well as levers for gear, flaps and spoilers.

Three CRTs were used to depict CAMA's primary flight displays, the navigation display and a third supplemental display, each equipped with touch screens. In order to enable low level flying from the experimental cockpit, which is located in the passengers bay of the aircraft. A LCD-projector provided an outside view taken from a video camera in the aircraft's cockpit, enhanced by a 3D head-up display overlay.

Furthermore, appropriate installations were made to enable verbal communication between CAMA and the pilot. Speech output was derived using a DEC *DecTalk* System, for speech recognition a SUN *SSI* system was integrated. The CAMA main modules were hosted by two SGI workstations interfaced via ethernet to the core avionics system of ATTAS. (See Figure 10 for an overview of the hardware set-up.) In order to be compliant with the experiments previously conducted in the simulator trial a similar mission was prepared and agreed with ATC.

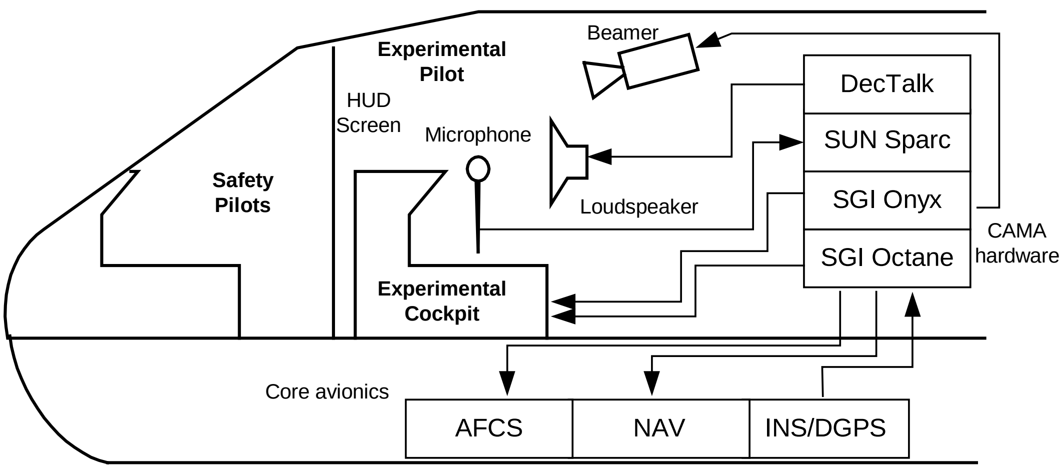


Figure 10 Integration of CAMA hardware into ATTAS

Takeoff was from Landsberg air base near Munich. An IFR-transit flight via ATC routes led the aircraft to the gaming area located over the Black Forest area in Germanys south-west, which provides sufficiently structured terrain for realistic tactical terrain masking. Here low-flying had to be performed until the target point was reached and a simulated drop procedure was carried out. The altitude flown during the low-level segment was at a minimum of 1,000 ft above ground due to safety considerations. After leaving the battle zone, IFR-flight was again performed back to the home base. The duration of the flight was about 1.5 hours.

During the mission the pilot had to handle typical piloting tasks. Changes in air tasking and airspace co-ordination order repeatedly called for re-planning. In addition other scenario elements like adverse weather conditions and surface-to-air missile sites were simulated.

Subjects

During the two CAMA flight trial campaigns a total of five German Air Force transport pilots from the Air Transport Wing, Landsberg were envolved as subjects. They were rated combat ready on C-160 *Transall* and had logged 850 and 4200 hours as pilot in command. The second campaign was supported by two test pilots from the Technical and Airworthiness Centre for Aircraft, Manching. During the campaigns eleven missions were conducted. Only one mission was corrupted by serious hardware problems, so that this mission could not be considered for evaluation.

4.1.3 Evaluation results

The evaluation was performed mainly to demonstrate the technical feasibility of a complex crew assistant system being operated under real-world conditions. In order to assess the pilot’s overall acceptance of the approach and benefits offered by the cockpit assistant system, a de-briefing session concluded the experiments, where the pilots were asked to fill out subjective ratings.

The methodological approach to the subjective evaluation of CAMA followed a certain scheme of questions, which has been derived from the considerations mentioned below. Rouse (1991) proposes the following aspects for the evaluation of man-machine-systems:

- *Compatibility*: Is the system adapted to the operators capabilities and limitations?
- *Intelligibility:* Does the organisation and the contents of the man-machine-dialogue provide a meaningful communication?
- *Effectiveness*: To what extent does the system enhance task-performance?

According to Johannsen (1993), meeting these three criteria is a prerequisite to reach a high degree of acceptance for the man-machine-system. Another important aspect for the evaluation of a crew assistant system is the term of situation awareness. Endsley (1988) defines situation awareness as follows:

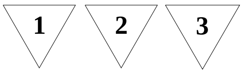
> “Situation awareness is the perception of the elements in the environment ... , the comprehension of their meaning, and the projection of their status in the near future.”

Therefore, the questionnaires were structured according to the following aspects:

- In order to evaluate the situational awareness aspects, the considered situation space was classified and structured into classes and sub-classes of relevant situational elements. Again, with regard to these classes the pilots had to indicate whether they had all the situational element-related information at their disposal whenever needed.
- The effectiveness and the benefit provided by the functions were evaluated by listing all relevant tasks and sub-tasks throughout the mission. The subjects had to comment on the quality of assistance provided by CAMA with respect to these tasks.
- To evaluate the degree of acceptance, the pilots had to refer to a list of statements characterising the system behaviour and handling features.

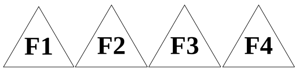
All ratings were given on a scale of 1 to 7, where 1 represents the best evaluation and 7 marks the negative end of the scale. The markers depicted on the following ratings stand for:

Simulator trials 1, 2, 3:



Median values from 10 different pilots after having flown the mission for the first (1), the second (2) and the third time (3)

Second flight trial:



Exact value from four individual ratings (1 - 4) after having flown live-missions

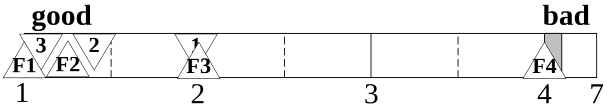
The following aspects were assessed:

Situation awareness

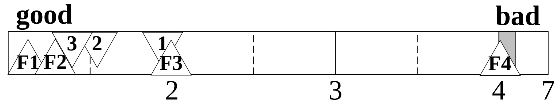
In order to evaluate the situational awareness aspects, the situation space considered was classified and structured into classes and sub-classes of relevant situational elements. The pilots had to give their impression of the specific awareness qualities. Figure 11 shows some selected results.

"How would you judge your overall awareness concerning ... during flight?"

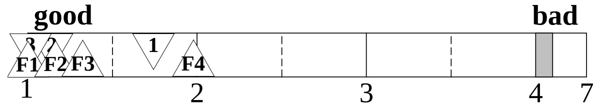
a) "aircraft attitude"



b) "terrain relief"



c) "threat along low-level trajectory"



d) "being aware of my own faults"

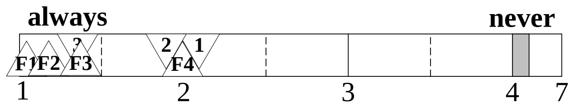


Figure 11: Ratings concerning situational awareness

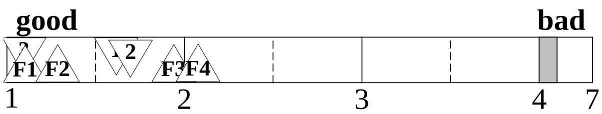
Results 11a-d basically confirm the findings from the simulator trial. The rather critical rating of one pilot in Figure 11a and b indicate some problems with the enhanced vision terrain depiction on the HUD in combination with the unusual out-of-the-window view provided through a video set-up (see above).

Assistance Quality

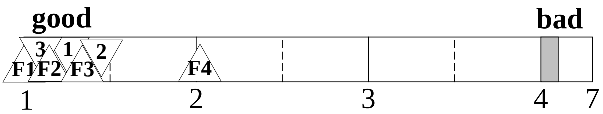
Here the pilots were asked to rate quality aspects of the assistance provided by CAMA while conducting typical mission tasks.

"How did CAMA assist you in ..."

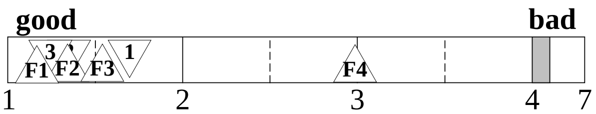
a) "complying with mission constraints (ACO/ ATO)?"



b) "planning the low level routing?"



c) "updating flight plan due to ATC clearances/ orders?"



d) "performing low-level flight guidance & navigation?"

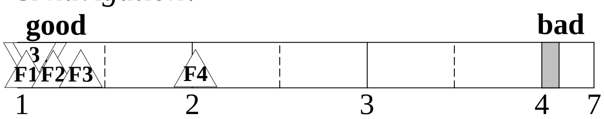


Figure 12: Ratings concerning assistance quality

Figure 12 a&b also confirm the results found in the simulator trails. Rating c can be explained by the shared responsibility for ATC-communication between experimental and safety pilots. Slight deficits in the ratings as compared to the simulator trials are certainly induced by a lack in familiarisation with the experimental set-up.

Handling Quality and Acceptance

The acceptance was determined by subjectively evaluating the behaviour of the assistant system as well as its handling qualities. For example the appearance of CAMA's monitoring and advice functionality as well as the general handling had to be rated.

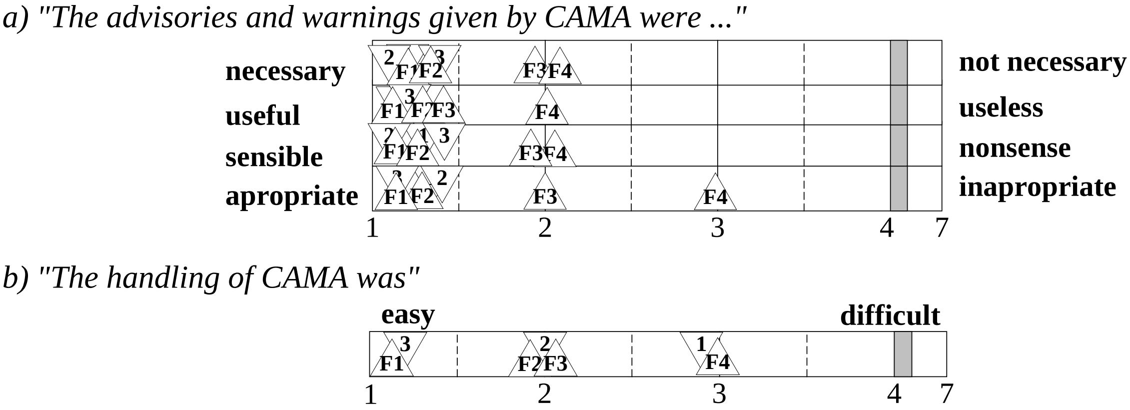


Figure 13 Ratings concerning handling quality and acceptance

Deficiencies in the advisory behaviour (Figure 13 a), which resulted in erroneous warnings, could be traced back to insufficient adaptation of CAMA's intern user model to ATTAS procedures. Overall handling quality, though, proved to be unchanged compared to the simulator runs (Figure 13 b).

Summary

CAMA and its various assistant functions have previously been evaluated during two experimental campaigns utilizing a flight simulator. In spring and fall 2000 CAMA was tested for the first time in in-flight trials in two separate campaigns. The CAMA system was installed on-board the ATTAS experimental aircraft. Special provisions, e.g. a video outside view had to be made to enable low-flying from the experimental cockpit located in the passengers bay.

Professional military pilots performed a total of eleven transport missions. In the de-briefing sessions the pilots gave generally positive ratings to the system, its contribution to situation awareness, the quality of the assistant functions, and the degree of acceptance of such an electronic crew member. A few less positive ratings had to be accepted in certain areas. These can mainly be attributed to shortcomings in the familiarisation of the subjects with the experimental environment as well as the limits of the adaptation of CAMA's functionality to the ATTAS aircraft. The promising results gained in the simulator trials could nevertheless be confirmed.

4.2 Tactical Mission Management for Attack Aircraft

In order to prove the cognitive system approach in the field of military fighter aircraft, the Tactical Mission Management System has been implemented as a functional prototype and integrated in the flight and scenario simulation environment at ESG. It has undergone an experimental evaluation with operational personnel in spring 2001. The following sections give details on the experimental design and the evaluation results.

4.2.1 Functional architecture

In order to derive a functional breakdown of the TMM the generic processing steps are translated into specific functions (see Figure 14 and Figure 5 as a reference). On the state-oriented layer situational parameters such as aircraft sensor and system signals, data-link information such as tactical elements and mission order, and on-board database entries e.g. terrain elevation data are to be considered. These data are analysed in order to identify context-specific features concerning pilot behaviour, aircraft movement and the external tactical situation. The monitoring of the threat accumulation along the planned trajectory is a typical example for a context-spanning analysis.

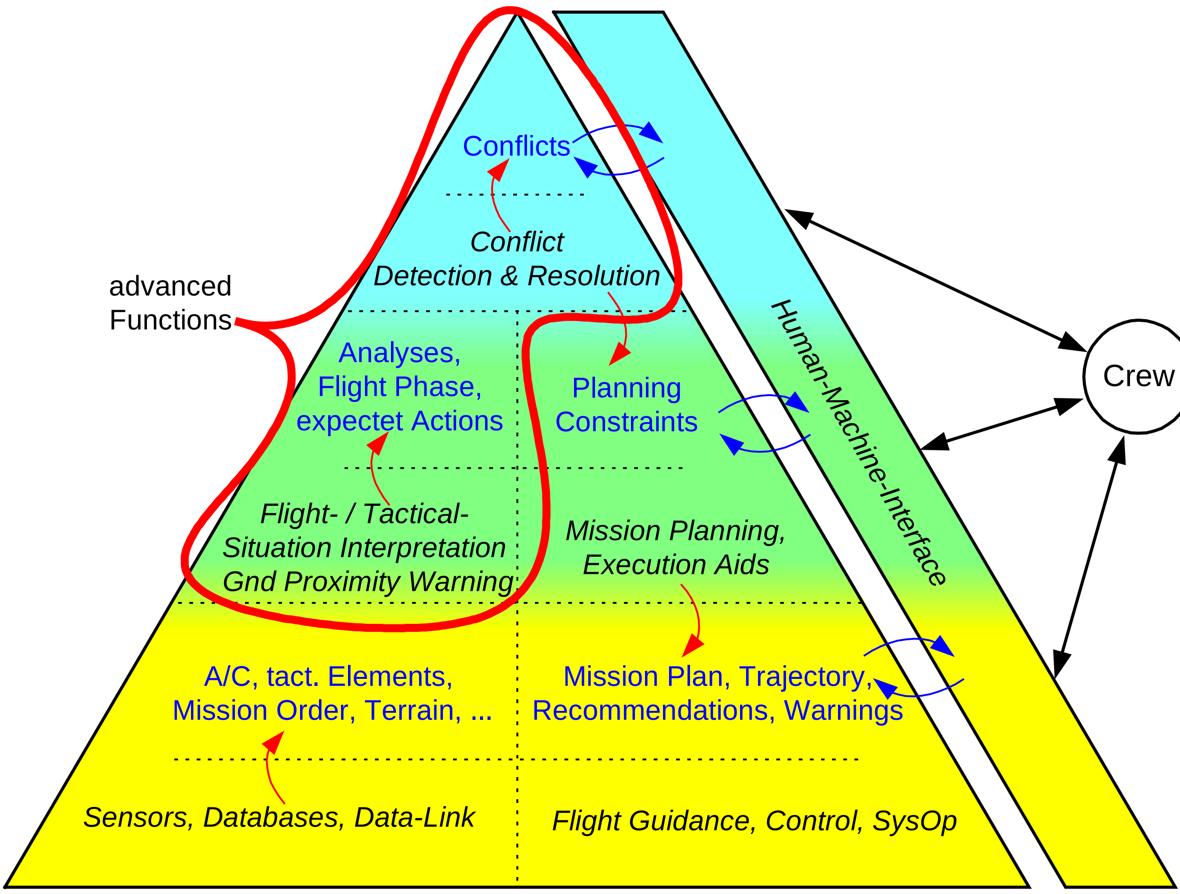


Figure 14: Functions of machine problem solving for mission management

The determination of the current phase of flight is essential for the model-based prediction of expected crew actions required to cope with the mission constraints. It considers all relevant task domains such as flight guidance along the pre-planned track, systems operation, weapon deployment, as the human operator does. It computes the current tasks and task parameters relevant for the crew in the present situational context (see Figure 8).

The *conflict detection and resolution* function builds up a hierarchy of general goals to be followed throughout the mission, such as flight safety, combat survival and mission accomplishment (see Figure 7). Utilising the results of the tactical situation interpretation and the monitoring of the flight situation-dependent tasks, the system figures out violations of these goals. After negotiation with the pilot, a proposal how to resolve the conflict will be passed to appropriate machine agents for conflict resolution. Implementing this human-like goal-task-model ensures machine problem solving strategies which are easy to anticipate for the pilot.

Planning is the most important conflict solving agent activity. The tactical mission management system offers a fully autonomous mission and route planning capability to the crew, including terminal operations planning, transit flight planning, tactical low-level flight trajectory planning and the use of attack procedure templates. Feedback is obtained in two ways; externally, due to manipulatory action of the crew and, thereby, alteration of the situation; and internally by the continuous re-consideration of the planning result in terms of goal integrity.

Finally, the Tactical Mission Management System provides an appropriate *man-machine interface* on the flight deck, in order to manage the information flow and the crew interactions. The main components are an advanced primary flight display utilising a perspective 3D synthetic vision symbology, a tactical mission management and navigation interface, and speech synthesis.

4.2.2 Experimental design

In order to prove the approach, the TMM has been implemented as a functional prototype and integrated in the flight and scenario simulation environment. It has undergone an experimental evaluation with operational personnel in spring 2001. The following sections give details on the apparatus, scenario and tasks as well as the subjects.

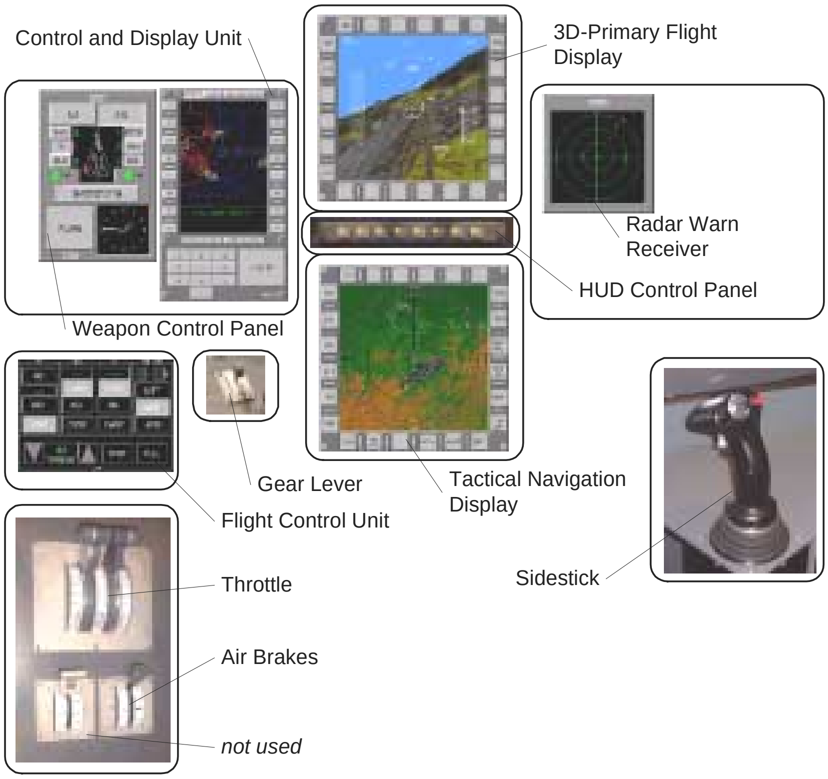


Figure 15: Cockpit in the TMM configuration

Apparatus, scenario and tasks

For the evaluation of the Tactical Mission Management System a comparative study was chosen. Two different simulator set-ups were configured, on the one hand representing the basic functions of a reference combat aircraft cockpit (e.g. Tornado) and on the other hand demonstrating the TMM functions and displays (Figure 15). Following the experimental procedures the pilots had to perform a dedicated test mission with each of the cockpit configurations. Figure 16 shows the phases of the test mission located in the south-west regions of Germany i.e. (1) tactical transit, (2) low-level ingress, (3) attack, (4) low-level egress and (5) tactical transit. During the low-level phase the mission was supported by computer-generated units such as SEAD-forces for suppression of enemy air defence and AWACS. Using the TMM-configuration the aircraft was participant of a tactical data-link network providing data on other participants and surveillance information. During the mission the tactical situation (i.e. hostile SAM sites) was supposed to change several times forcing the pilots to react accordingly (e.g. route adaptation, re-planning, threat avoidance), thereby workload being imposed on the operator.

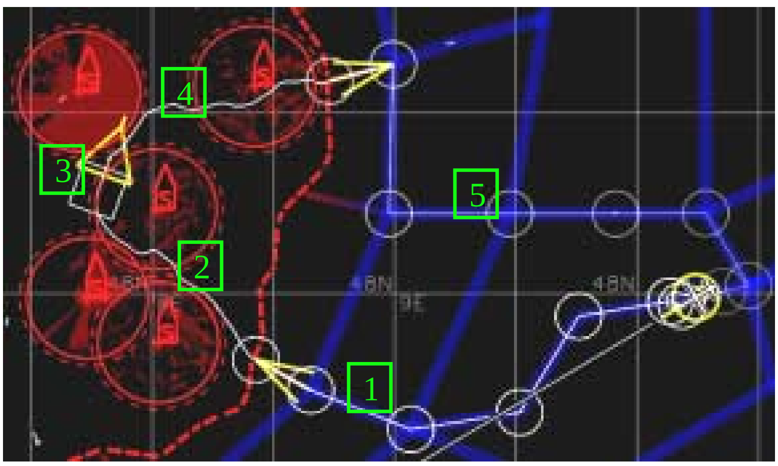


Figure 16: Scenario of the test mission for system evaluation

Subjects

The subjects were four German Air Force pilots (partly flight instructors) from the Fighter Bomber Wing 34, Memmingen at an age of 30 to 38 years. Their flight experience ranged from a total of 900 to 3000 flying hours on Tornado and other NATO combat aircraft. During a one day familiarisation phase the pilots had the opportunity to train the handling of the simulator and the interaction with the TMM before the test mission had to be performed.

4.2.3 Evaluation results

The main scope of the evaluation of the Tactical Mission Management System was to account for improvements in comparison to the reference system in terms of the following categories of measurements:

- Measurement of pilot performance
- Evaluation of system performance of the TMM
- Evaluation of pilot's workload
- Measurement of pilot's situation awareness
- Subjective ratings concerning TMM performance

The following paragraphs report on the specific results.

Pilot's performance

The investigation of the pilot's performance has been conducted under the consideration of the three abstract goals as defined earlier in this paper: flight safety, combat survival and mission accomplishment.

Table 1: Violations of minima during low-level flight

REF	*< 0 ft AGL*	*< 50 ft AGL*	*< 150 ft AGL*
Pilot 1	1	5	39
Pilot 2	0	0	17
Pilot 3	1	3	19
Pilot 4	1	9	36
TMM	*< 0 ft AGL*	*< 50 ft AGL*	*< 150 ft AGL*
Pilot 1	0	0	2
Pilot 2	0	0	5
Pilot 3	0	0	5
Pilot 4	0	1	23

With regard to *flight safety*, the area of low-level flight guidance has been investigated. During the experiments it could be observed that pilots frequently took the risk of dangerous ground and obstacle proximity in order to avoid military threats. Therefore, it was investigated how often certain given above-ground-level minima were violated while performing low-level flight. Table 1 gives the results of the comparison between the reference system (REF) and the Tactical Mission Management System (TMM). The assessment of ground collisions and the frequency of AGL minima violations make clear that the TMM caused a significant risk reduction by a better ground separation. In a deeper investigation of the terrain following performance (Schubert & Schulte, 2001) it is evident that the flown vertical profile becomes significantly smoother (i.e. less vertical acceleration, less variation in altitude) in the TMM configuration. Thereby, the pilot's comfort level could be increased.

An important feature of the TMM is the ability of situation-dependent in-flight re-planning of the mission plan for threat reduction. In order to quantify the effect of this assistance function in terms of *combat survival* the mean threat exposure has been evaluated along the flown trajectories (Figure 17). Obviously, a massive reduction effect on the threat exposure could be noted by use of the TMM. It should be emphasised that the improvement of threat avoidance with the TMM could be achieved in combination with a much better ground separation (see Table 1).

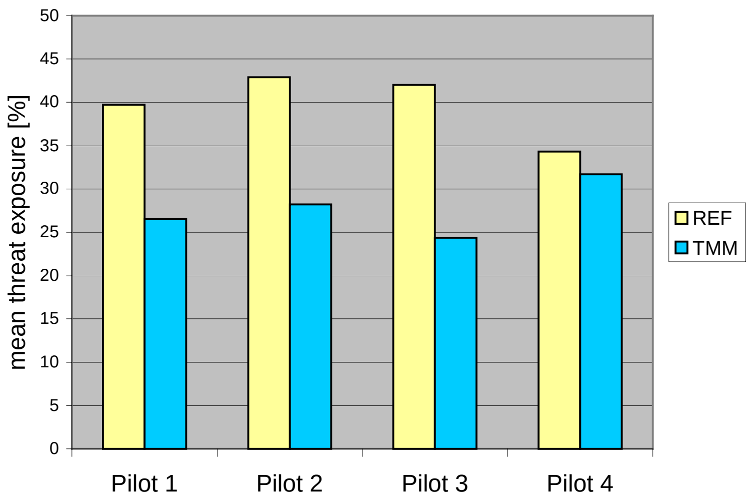


Figure 17: Mean threat exposure in comparison

Table 2: Global criteria of flight safety and mission accomplishment

	Pilot 1		Pilot 2		***Pilot 3***		***Pilot 4***	
	REF	*TM M*	*REF*	*TM M*	*REF*	*TM M*	*REF*	*TM M*
SAM shots [#]	-	-	-	-	1	-	1	-
ΔTOT [s]	L 8.0	E 0.4	E 0.3	E 2.1	E 2.3	E 0.2	L 3.8	L 2.1
Target hit	OK	OK	OK	OK	OK	OK	OK	OK
Destination reached	OK	OK	OK	OK	OK	OK	no	(OK)
Fuel on Board @ Touch down [%]	4.4	14.3	9.1	13.8	4.3	12.5	0.0	8.8
ACO violations	5	-	5	-	5	-	8	-
Mission accomplished	no	OK	OK	OK	no	OK	no	(OK)

Table 2 provides a collection of criteria concerning *mission accomplishment*. The results make evident that the pilots performed notedly better with the TMM than without. Due to a better threat avoidance with the TMM the SAM shots could be reduced. Performance criteria such as meeting the Time-over-Target (TOT), hitting the target or reaching the destination could be fulfilled by all pilots quite well. Only pilot 4 did not reach the destination with the reference system due to a flame-out condition. In general it was found that fuel consumption could be decreased significantly with the TMM during the mission. Another observation was made concerning the number of violations of the Airspace Co-ordination Order (ACO) routing, which could be totally eliminated by the use of the TMM. So, the risk of being hit by friendly fire was minimised.

System performance

One of the most important features of the TMM is the pilot assistance in optimising a threat minimal route under a dynamically changing hostile threat theatre. Figure 18 shows the total and mean threat exposure computed with an underlying worst-case scenario. Comparing the threat exposure of a direct routing (1st column) with the result of the low-level route planner of the TMM (3rd column) makes the advantage obvious. The total threat accumulation could be decreased from about 8500 to 5700 *%km*. Due to the longer flight trajectory, the effect on the relative threat exposure is even more noticeable (55 down to 30%). The columns 2 and 4 in Figure 18 show the threat values of the actual flown trajectories, again under consideration of a worst-case scenario. It is obvious that the co-operation between the system and the pilots yields another improvement in terms of threat avoidance due to synergetic effects.

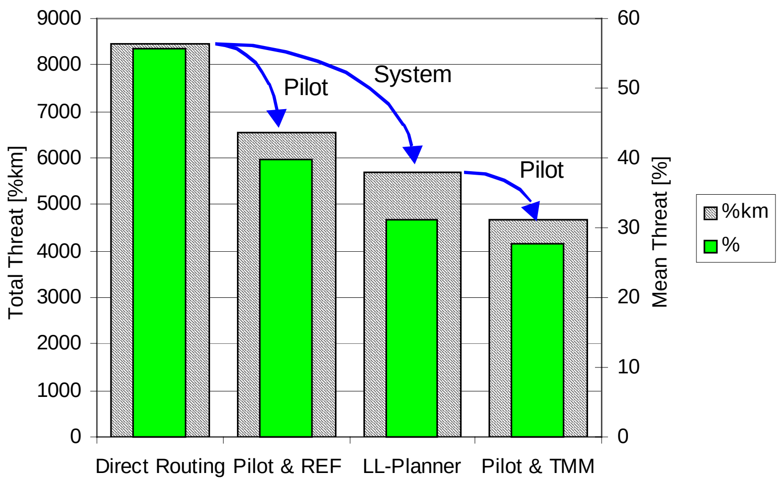


Figure 18: Threat exposure reduction

Workload and situation awareness

The TMM was designed to reduce the operator's workload by providing functions to support a better situation awareness and particular automation functions. During the experiments measurements of situation awareness and workload were conducted. Therefore, the experiment was stopped at dedicated points of time in order to perform the NASA Task Load Index (TLX) and the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1988).

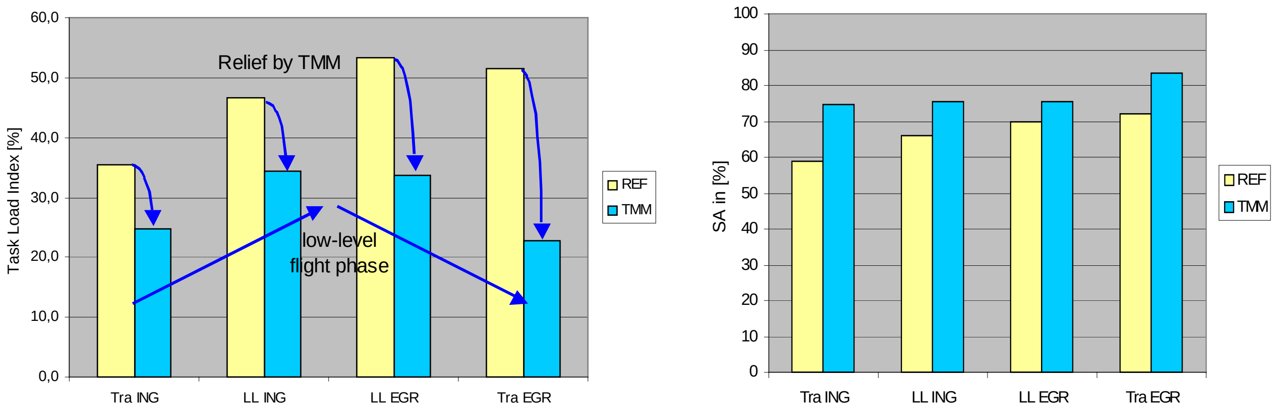


Figure 19: NASA TLX (left) and SAGAT (right) results over mission phases

The evaluations were conducted four times each experimental run (reference system and TMM). The measuring points were the task situations 1 (Transit Ingress), 2 (Low-level Ingress), 4 (Low-level Egress) and 5 (Transit Egress) according to Figure 16. Figure 19 shows the results of the assessments averaged over the four subjects. Concerning the NASA TLX rating (see Figure 19, left) it was found that the overall workload could be reduced massively by use of the TMM with an expected slight increase of workload during the low-level phases of the mission. The situation awareness assessment was based upon the evaluation of a total of 26 multiple-choice questions concerning situational features. Figure 19 (right) shows the weighted results. An increase in situation awareness of about 10 to 15%, in particular during the early mission phases, can be observed.

Subjective ratings

For a further evaluation of the system performance the experimental subjects had to give subjective ratings by the use of questionnaires in a de-briefing session at the end of the two day evaluation period. The main aspects of the survey were the evaluation of

- system performance of the TMM,
- acceptance of the TMM by the user, and
- overall assessment.

The rating scales covered a range of values from 1 to 7 and were each labelled by a pair of antithetic terms (e.g. good – bad; agree – disagree). The following paragraphs report on some selected results.

Figure 20 shows the pilots' evaluations of the quality and performance of the assistance functions offered by the TMM. The overall assessment can be regarded as very positive. Although, there can be identified some minor objections caused by unfamiliar display of timing and system information, insufficient training with the system and some shortcomings in pilot's behaviour modelling. Despite these (easy

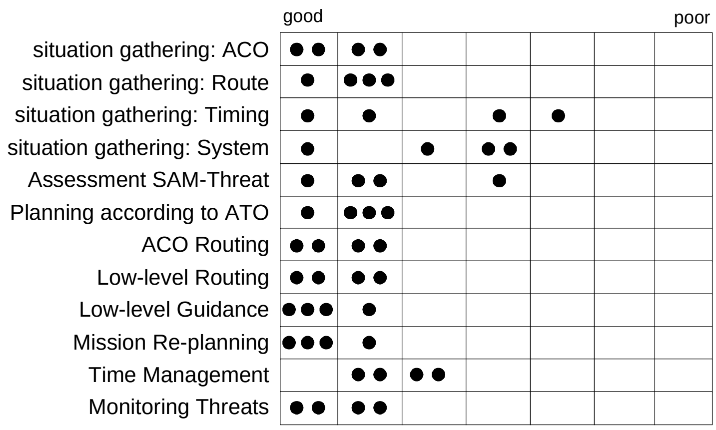


Figure 20: Evaluation of assistance quality

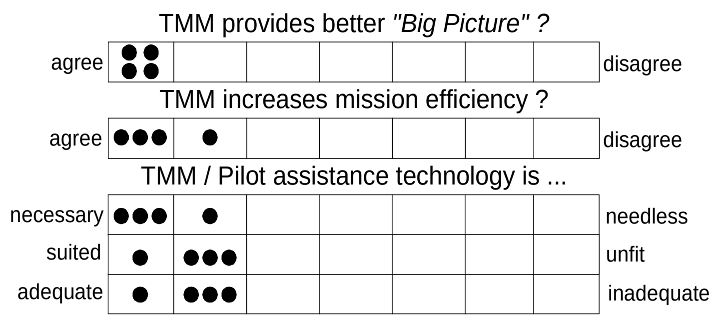


Figure 21: Overall assessment of the TMM

to remove) deficits the assessment of the implemented prototype was almost optimal.

Figure 21 shows some selected but representative results of the overall assessment given by the pilots. The subjects fully agreed with the hypothesis that the TMM provides a better *big picture* in terms of global situation awareness. TMM is qualified to increase mission efficiency according to the pilots. The operators regarded the presented technology of Tactical Mission Management and crew assistance to be absolutely necessary, suited and adequate.

5 CONCLUSIONS

After having gathered years of experience in cognitive flight-deck automation and crew assistance, the time has come to gain the results of exceedingly successful efforts in the field of military transport as well as combat aircraft. The functional breakdown of the *Crew Assistant Military Aircraft* (CAMA), representing the air-transport domain, and on the other hand the *Tactical Mission Management System*, being a cockpit automation system for combat aircraft, has been derived from a model of human information processing, in order to approach a co-operative automation principle. Laboratory prototype systems have been evaluated with Air Force pilots in simulator and flight trials. Besides the fact that the approach was very well appreciated by the pilots, objective measures evidence a significant increase in performance in terms of threat avoidance and mission efficiency. These results could be achieved in conjunction with a noticeable reduction of the terrain collision risk and the operator's workload. Therefore, the system approach is highly recommended for application in the advancement and automation of future aircraft as well as other military and non-military application domains, where ever operator situation awareness and decision-making is crucial.

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On-Board Decision Support through the Integration of Advanced Information Processing and Human Factors Techniques: The POWER Project

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Summary

As advanced crew support technologies will be available more and more in future military aircraft, it is necessary to have a good understanding of the possibilities in this area, taking into account operational demands, technical possibilities, human factors, evaluation, and validation aspects. A Crew Assistant (CA) is a decision support system for air crew, designed to improve mission effectiveness and redistribute crew workload in such a way that the crew can concentrate on its prime tasks.

The POWER (Pilot Oriented Workload Evaluation and Redistribution) project is a Netherlands National Technology Project. The project is aimed at demonstrating a generic CA environment and individual tactical decision support tools to military pilots in a simulated environment, the NSF (National Simulation Facility), a six-degrees of freedom cockpit in a visual dome.

The project is a technology demonstration project to show new CA features. An advanced software architecture has been set up, based on multi-agent technology, where software "agents" co-operate in sharing information and using resources on an as-needed basis. Each agent is an autonomous piece of software that is able to anticipate courses of action and performs its function pro-actively.

Several prototypes of crew assistant agents have been developed and integrated in order to facilitate a CA demonstrator

A large-scale experiment with operational pilots from the Royal Netherlands Air Force (RNLAF) has been carried out to demonstrate the effects of CA technology as decision support, to validate tools, and to measure the effects of on-board decision support in enhancing pilot situational awareness.

This paper describes the demonstration CA environment and provides insight into the different CA components. Part one describes the environment as a generic CA architecture that can be installed on a simple work station as well as in a full-scale simulation environment. The second part of this paper describes the aforementioned experiment, where NCMM and the contents of the experiment will be detailed.

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PART I: A CREW ASSISTANT ARCHITECTURE

1 Introduction

Software and human factors are becoming major part of current and future on-board avionics. Current developments in software engineering and advanced information processing techniques enable complex crew assistant applications, especially support of the aircraft crew in carrying out primary and secondary tasks is more and more provided by electronic systems. Application of crew assistants in fighter aircraft is a challenging task, both for the research and development of the software, as for the human factors aspects concerning its optimal use and trust of the pilot in the system.

The POWER (Pilot Oriented Workload Evaluation and Redistribution) project, is a Netherlands National Technology Project. The project is aimed at demonstrating a generic Crew Assistant (CA) environment and individual tactical decision support tools to pilots in a simulated environment, the NSF (National Simulation Facility), a six-degrees of freedom F-16 cockpit in a visual dome. This demonstrator has been the focus of the project.

Current progress in advanced information processing, new advances in human factors, and the possibility to validate new avionics so that pilots learn to trust the system, form the basis for this paper in order to support RNLAF in the acquisition and usage of new aircraft. In this paper, a generic simulation environment is discussed, that enables different levels of crew assistant demonstration and experimentation. The environment proposed is based on multi-agent technology, where a generic Crew Assistant environment can be plugged onto a "simple" scenario generator on a work station or to a full-scale flight simulation facility, like the NSF.

Several prototypes of CA agents have been developed and integrated in order to facilitate the CA demonstrator:

- A profile recognition agent takes input from different sensors and recognises profiles in a data fusion assembled picture. The agent reasons with uncertainty in the observation and uses Bayesian Belief Networks to model the profile and sensor's characteristics.
- A manoeuvre prediction agent assesses an opponent's manoeuvre and predicts the patters that will be flown when in air-to-air combat. This tool is based on case-based reasoning technology.
- The NCMM (NLR counter Measure Manager) agent advises counter measures against threats, e.g. SAM-sites. The tool is based on expert system technology.
- An HMI is designed with an NLR built tool, NADDES (NLR Avionics Display Development and Evaluation System), for increasing pilot situation awareness.

This paper will provide an overview of the POWER project. It has been set up in two parts, where the first part describes the generic CA architecture and part two describes a large scale experiment that has been carried out. Chapter two will introduce crew assistant technology and chapter three will describe the software architecture, which is based on multi-agent technology. Chapter four describes the technical aspects of the simulation environment the experiment. Chapter five describes the setting and results of this experiment.

2 Crew Assistant Technology

Fighter pilot's workload is rapidly increasing. Modern military operations take place in a complex environment to accomplish a spectrum of missions. The most important factor in the increase in workload concerns the operational environment of current fighter aircraft:

- the increase of the complexity of the military environment in general (e.g. combined joint task forces, peace keeping/peace enforcement).
- the increase of the complexity of the types of missions to be flown.
- the increase in the number of different (kinds of) threats.

Another factor is the technological developments of fighter aircraft. The increase in aircraft speed and aircraft types and on-board systems causes the aircraft itself to become much more difficult to manage, putting more pressure on the crew. During high-stress situations, the crew can get overloaded with information, while it has to perform a multitude of actions. Figure 1 illustrates the possible information overload and decision making process.

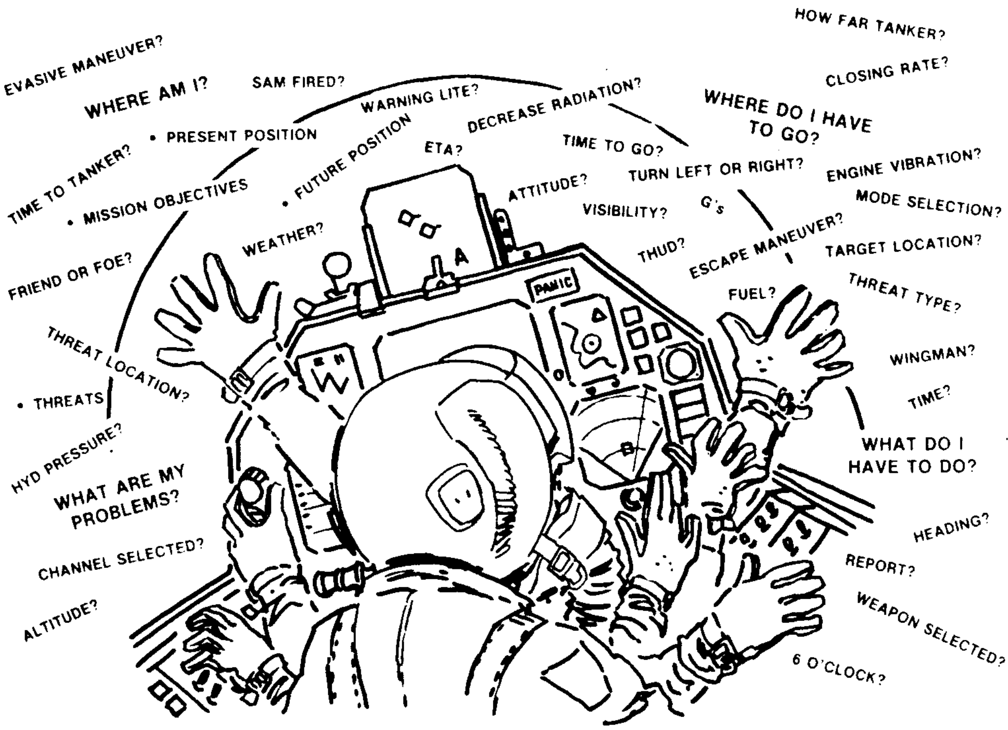


Figure 1. The information requirements of the crew [Yannone, 1985].

A Crew Assistant is an on-board decision support system that supports the crew in performing its mission. It aims at improving mission effectiveness, flight safety, and/or survivability by providing the crew with concise and relevant information, depending on the mission phase, thus enabling the crew to concentrate on mission decisions and make more effective decisions. [Urlings 1995]. Crew Assistants are decision support systems for air crew, designed to improve mission effectiveness and redistribute crew workload in such a way that the crew can concentrate on its prime tasks. Ideally, a CA assists a pilot, or other crew members, by providing the following kind of functions:

- Acquire the necessary information and merge the input from different sensor and information systems into one timely and consistent view of the current situation (the status of different on-board systems, the situation outside, etc.).
- Process the merged information to give advice (weapons selection, route planning, tactics evaluation, fuel management, etc.).
- Perform tasks autonomously when so instructed by the pilot or another crew member (autopilot, target tracking, systems monitoring, etc.).

As advanced crew support technologies will be available more and more in future (military) aircraft, it is necessary to have a good understanding of the possibilities in this area, taking into account operational demands, technical possibilities, human factors, evaluation, and validation aspects.

The current state-of-the-art in advanced information processing now makes intelligent pilot assistant through a CA technically feasible, including real-time on-board data acquisition, fusion, and processing. Advanced information processing techniques, like expert systems and neural networks, and methods for constraint reasoning, case based reasoning and reasoning with uncertain and incomplete information, can be used in the military cockpit. Research in Human Factors technology aspects, will make the techniques available to the human operator. For an overview of systems and technologies, see e.g. [Boers 1999], [Van Gerwen 2000-1], [Verhoeven 2000].

In the course of the years, several CA programs have been set up. The Crew Assistant Military Aircraft (CAMA) is a German DoD programme that investigates the use of an intelligent electronic crew member in the military transport application [Strohal 1997], [Frey 1999]. Within the programme, flight simulator trials have been performed in the simulator of the University of the German Armed Forces. Flight experiments are scheduled in an in-flight simulator. Hands-on experience and feed back from pilots is a factor in the development of systems that must be gained. One project that takes a human factors perspective on CAs is the Cognitive Cockpit (COGPIT) project, that has been set up by the UK Ministry of Defence in conjunction with the Defence Evaluation Research Agency (DERA). This project seeks to develop a theoretically grounded, human-centred approach for guiding a principled development of intelligent pilot aiding concepts for cockpit automation [Taylor 1998], [Taylor 2000]. It researches the cognitive engineering aspects of the pilots to couple knowledge-based systems for situation assessment and decision support with conceptsand technologies for adaptive automation and cockpit adaptive interfaces. Other CA projects are Pilot's Associate (PA) [Holmes 1991], Rotorcraft Pilot's Associate (RPA) [Collucci 1995], CoPilote Electronique, Cockpit Assistant System (CASSY) [Onken 1997], and the Electronic Copilot (ECOP) [Stein 1987].

These programs take either a technological or a human centred focus on CAs. We believe that for a good integration of CA technology in the cockpit, the relationship between the fields of Advanced Information Processing (AIP) and Human Factors (HF) should be exploited further. The POWER project brings together the fields of military operations research, advanced information processing and human factors. It combines techniques from artificial intelligence and human machine interaction in such a way that pilots are supported with advanced crew assistants, wherewith the information is provided to them in a sense that a fused picture of the world emerges. Apart from the technological aspects, the POWER project has strong roots in the analysis of requirements and needs from operational fighter pilots. The project will help decision makers in technology assessments for acquiring new aircraft and equipment and manufacturers in making strategic decisions on technological programmes.

In many cases, information will be time dependent, inaccurate and incomplete. The use of uncertain and incomplete information should be further investigated and must be considered in the design of the Human Machine Interface (HMI). The project therefore, focuses on the following challenges:

- Provide a flexible demonstration environment for crew assistant technology, based on operational demands from fighter pilots.
- Provide examples of crew assistant technology, based on new advanced AIP and HF aspects.
- Provide insight in new real-time reasoning techniques for reasoning with uncertainty.
- Provide a quantitative scientific base that proves the benefit and user acceptance of CA technology.
- Perform experiments with the demonstration environment that lays a basis for further work in the field of introducing CA technology to the RNLAF.

3 The Architecture

Until recently, work in on-board automation focussed on the introduction of single self-supporting functions. The advantage of this is high reliability in case of single failures, where other independent systems take over. Instead of relying on the information that one sensor provides, CA decision support functions in essence focus on the integration of information and the provision of a complex and fused picture to the pilot. This creates new demands for the software and hardware architecture and the human factors aspects.

Decision support functions are concerned with data acquisition, fusion, and processing and use information from different sources, so that an architecture is needed, where the system does not rely on one information source and does not contain any critical processing nodes. We believe that an architecture based on agent technology can and will play an important role in the near future in avionics. Agent-based architectures have been introduced for on-board decision support systems in e.g. TANDEM [Barrouil 1999], the Cognitive Cockpit [Taylor 2000], and for on board multi-sensor data fusion [Bossé 1999].

The strength of software agents is that they can be made to interact with other software agents or human users. Agents are “small” autonomous black boxes, which handle their own clearly defined tasks. A system of agents that co-operates is called a multi-agent system. Agents, if well-designed as separate processing units, enable communication between multiple subsystems, without putting a strain on one specific part of the system. Their loose coupling provides a possibility to introduce new technology throughout the aircraft's lifetime, especially at "end of the line" functions, like weapon systems, where it is relatively easy to validate new technology.

This chapter will give an overview of the proposed multi-agent architecture and will describe the most important CA components that have been provided with the POWER project.

3.1 A Functional Architecture based on Multi-Agent Technology

The proposed architecture has been based on the results of earlier projects, like the EUCLID (European Co-operation for the Long Term in Defence) Research and Technology project 6.5 [Zuidgeest 1995]. This NLR-led project on CAs for military aircraft started with extensive user interviews to establish an inventory of operational user problems and needs for pilots flying F-16, Tornado and AM-X. The project came up with a generic on-board CA architecture and indicated a challenge in the application of multi-agent systems and knowledge based systems.

The architecture that has been set up for the POWER project distinguishes four groups of functional agents. The groups are (1) data and information input agents, like sensors and the multi-sensor data fusion agent, (2) data processing agents which form the actual crew assistant functions, (3) information output agents mainly to the pilot, and finally, (4) the weapon agents. Apart from these, other agents perform functions for controlling and monitoring the overall system's status and health. In this paper, we will focus on the functional part of crew assistants, see figure 2.

The four functional groups further subdivided in seven subgroups (see slight colour differences in figure 2), discussed below.

Internal sensor agents are system components that transform the raw input data from the sensor hardware to an understandable format for the Multi-Sensor Data Fusion (MSDF) component. In our example, we included sensors to detect and distinguish SAMs and to detect incoming missiles.

- A Radar Warning Receiver (RWR) provides the position of ground threats, including an indication whether the SAM is in search, track, or guidance.
- The Missile Launch Warning (MLW) is a passive infrared plume detector that provides missile information while its motor is burning.
- The Missile Approach Warning is an active short range radar that detects a missile body, usually in a two to three miles range.

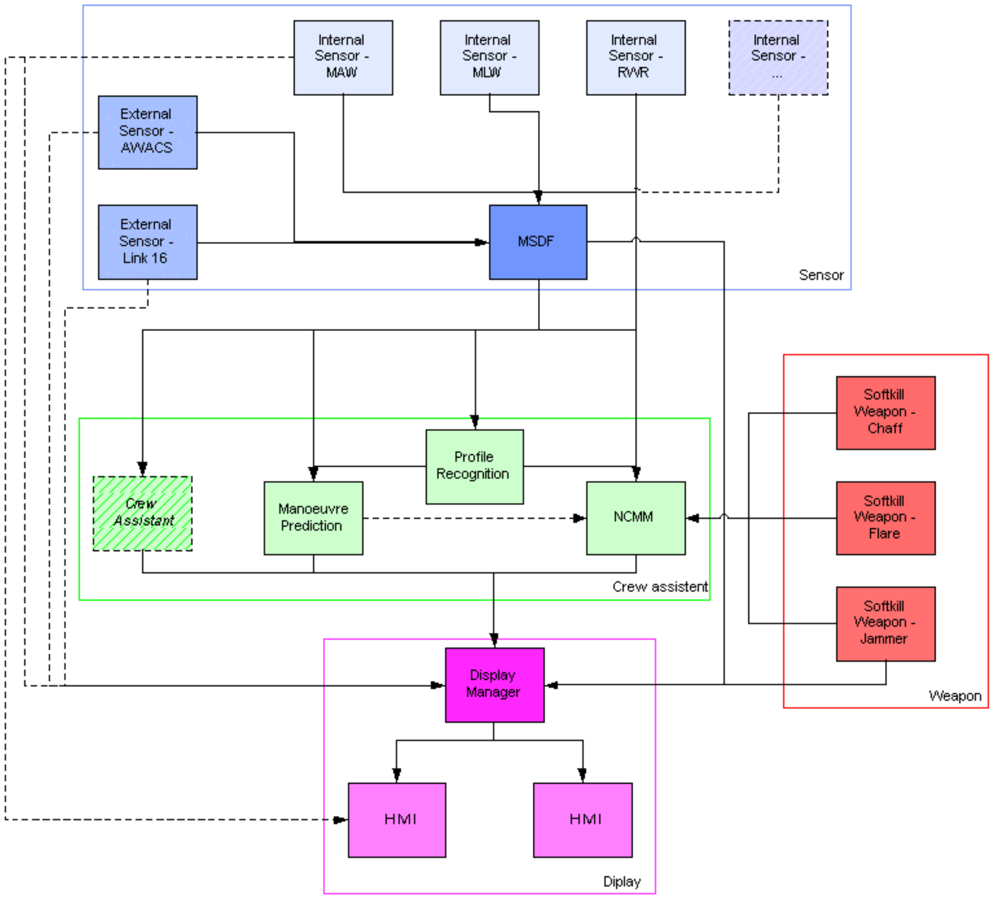


Figure 2. Functional architecture of on-board agents

External sensor agents are components that obtain their information from sensors or information systems that are physically located outside the aircraft, for example an AWACS or a Link-16. These sensor agents transform data and information into an understandable format for the MSDF agent or for the CA agents.

The Multi-Sensor Data Fusion agent combines the sensor information from all internal and external sensors into a combined sensor data picture. This agent may perform complex situation assessment tasks. In the current implementation, this is a fusion process that only provides the information to the CA's that is really necessary for the CAs to perform their task. Different projects have already shown the complexity of a multi-sensor data fusion process and have proposed architectures [TA-10], [Bossé 1999]. The latter proposes an agent based architecture for multi-sensor data fusion, which shows the flexibility of agent systems, where agents can delegate tasks to (sub-)agents.

Crew Assistant agents are the intelligent pilot support functions. The ones mentioned in figure 2 are elaborated in the POWER project (based on [Zuidgeest 1995]), however, the range of pilot support functions is not limited to these. CAs can be further classified into functions as information finding in the fused sensor picture (like profile recognition, see section 3.2), pilot advice (like manoeuvre prediction, see section 3.3, and NLR's Counter Measure Manager, see section 3.4 and chapter 4), pilot monitoring, mission monitoring, etc. Other classifications are possible, like [Barrouil 1999], [Taylor 2000].

Weapon agents control the weapon delivery. In this example, a number of softkill weapons to countermeasure ground threats is displayed. Their intelligence for example consists of providing the correct jamming against a recognized threat or dispensing a complex pattern of chaff and flare.

The Display agent is responsible for assembling an integrated picture of crew assistant information and for prioritizing information provision to the pilot. If necessary, it can hold information that is considered less important at a certain moment or less time critical, if the pilot is assumed to get overloaded with information. Once the situation is more relaxed, it can decide to provide this information. An even more intelligent display agent can decide what information should be provided on which cockpit display, or what information should be provided on which part of the cockpit display and automatically adapt the contents of the available displays if at (a certain part of) one of the displays an information overload is eminent. This technology, however, should be introduced with care [Verhoeven 2000].

The Human Machine Interface agent is the actual cockpit display that provides the information on the user interface. It may take inputs from the user.

For a generic CA demonstration environment, we require a crew assistant independently from its operational environment. Obviously, a generic demonstration environment, especially a complex one as a crew assistant requires a number of general tools, like scenario generation tools and environment databases. The currently developed environment connects the tools to ITEMS, which provides a topographical scenario and an F-16 aircraft model. This enables the possibility to connect the crew assistant to e.g. a fly box, see figure 3, to the NLR's F-16 mock up simulator, and to the NSF, see figure 4.

Figure 3. Flybox and workstation configuration

Figure 4. National Simulation Facility

3.2 Reasoning with Uncertainty for Profile Recognition

Reasoning with uncertainty will be an important aspect of CA technology. Even the information from a fused sensor picture will usually contain unclear elements. To investigate possibilities of real-time reasoning with uncertainty, a profile recognition agent was developed.

Any crew assistant will gather information from its environment, process this information, and act upon it. Probabilistic methods for reasoning with uncertainty have gained a lot of interest in the last few decades. The introduction of Bayesian Belief Networks [Pearl 1988], [Jensen 1996] made practical application of probabilistic reasoning possible. Most applications have been targeted at decision support in the medical domain where the variables in the model typically have a few states and no real-time constraints exist. In contrast, the decision support systems for fighter pilots have to deal with many real-valued sensor readings that provide measurements every split second and that need to be processed in real-time [Van Gerwen 2000-2].

Suppose an aircraft has on-board sensors to identify profiles. In this example, different profiles are considered and the aircraft sensors can measure length, width, and speed of the objects that are sensed. However, sensor accuracy depends on weather conditions, in particular visibility, cloud coverage, and humidity. This scenario is modelled through a Bayesian Belief Network as given in figure 5. Each of the profiles modelled, has an a-prior probability distribution.

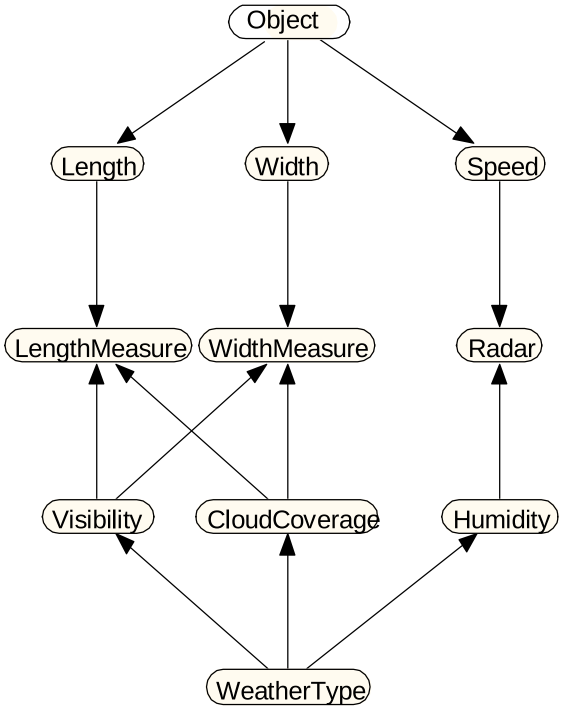


Figure 5. Bayesian Belief Networks for profile recognition

The goal of this research is to look into the possibility of creating an anytime algorithm for a Bayesian Belief Network. Anytime algorithms are algorithms that trade performance for time. As the amount of time is increased, an anytime algorithm improves the quality of the output. One of the features of anytime algorithms is that it can provide intermediate results at any moment, so that the available processing power and time can be regulated.

Propagating evidence in a Bayesian belief network can be a very time-consuming task (it is NP-hard). One solution might be an algorithm that uses state-space abstraction. We examined different AI techniques, like Breadth First, Breadth First Split, and Highest Belief First. Figure 6 gives the results of the different methods.

In the CA agent, we have shown that state-space abstraction in combination with a strategy such as Highest Belief First has interesting features required for an anytime algorithm. The proposed method outperforms simpler methods like Breadth First and Breadth First Split.

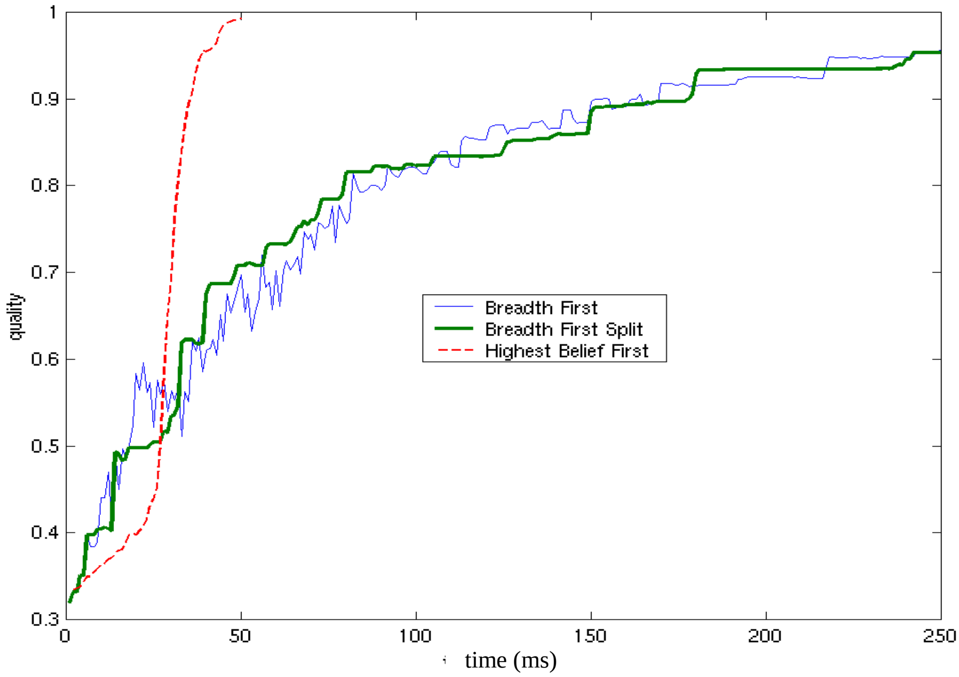


Figure 6. Running the BBN with different techniques to facilitate state space abstraction

3.3 Manoeuvre Prediction with Case Based Reasoning

The proposed Manoeuvre Prediction agent seeks to enhance the situation awareness of the pilot in a dogfight situation. Given information on the opponent's aircraft, like position and speed, the agent will try to determine the manoeuvre it is performing. Using this information, the agent can predict the future path of the opponent's aircraft. This information is then presented to the pilot, thus enhancing situational awareness.

The rapid changing environment in which such an application has to operate called for a strict real-time or any-time approach for the Manoeuvre Prediction agent. We also wanted to exploit the fact that every encountered dogfight involves manoeuvres that the application could use for future manoeuvre prediction.

It was decided, to use the case based reasoning technique from the field of artificial intelligence for implementing the Manoeuvre Prediction agent. The case bases reasoning technique will store cases (one manoeuvre is one case) in a database and provide means by which a newly encountered case can be compared to existing cases. The most similar case (manoeuvre) can be retrieved and used as source to indicated the encountered case. The newly encountered case will become part of the database for future use. This way of working is highly intuitive for humans, we learn from experience and try to recognise by comparing the current situation to past experiences.

The scientific challenge for implementing the Manoeuvre Prediction was to make the case based reasoning process work in real-time. We solved this by ordering the cases by individual elements of the manoeuvre (e.g. speed or distance from own-ship). Having an order in the database gives fast information where to look for the most similar case. In the end the search algorithm will quickly find the most similar case, but more importantly the algorithm will also perform well in anytime and will produce a fairly similar case, once interrupted.

Using the advanced software architecture of multi-agent technology the results from the Manoeuvre Prediction application are made available to the other applications (agents). These agents can use this information for their own purposes. The HMI agent will graphically display the information for the situational awareness of the pilot.

The NCMM agent may use this information to take counter measures based on the enemy's aircraft predicted position. The information may be sent to agents of nearby ground or airborne forces for their tactical decision aid or situational awareness.

3.4 NLR's Counter Measure Manager (NCMM)

The NCMM agent determines the most effective use of actors to counter detected threats. Such an agent enables co-ordinated counter measures that can not be performed manually using the separate systems. Most notably, this involves counter measures combining jamming and chaff. Furthermore, the manager can enhance effectiveness by combining counter measures to counter more than one threat simultaneously [Tempelman 1999], [Eertink 2000].

More information on the NCMM can be found in the second part of this paper, which describes an experiment to study the effects of decision support in the military cockpit and that has been carried out with the NCMM.

3.5 Display Development with NADDES

An HMI (Human Machine Interface) is designed with an NLR built tool, NADDES (NLR Avionics Display Development and Evaluation System) for increasing pilot situation awareness. NADDES is a development environment that has specifically been developed for the construction of avionics displays and as such, it provides a number of predefined components.

For the aforementioned demonstrations, separate HMIs have been developed. Since all demonstrations use the same development environment, they can easily be integrated to form one situation awareness picture for the pilot. The display manager agent decides which information to display on the available on-board HMIs.

An example of a NADDES developed HMI for the NCMM is given in figure 7.

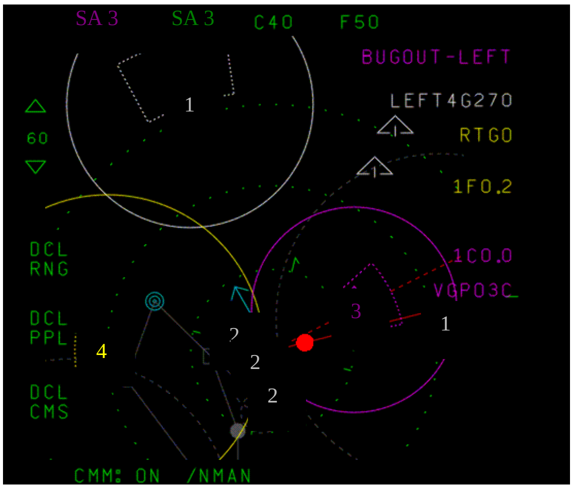


Figure 7 NCMM display

PART II: A THREAT MANAGEMENT DECISION SUPPORT EXPERIMENT

The second part of this paper describes a Crew Assistant and Situation Awareness experiment that has been carried out involving operational RNLAF pilots in the NSF simulator at NLR, Amsterdam. We will first give an elaborated overview of the NCMM tool that has been used and then focus on the details of the experiment.

The current military theatre becomes ever more complex and demanding for the pilot. This development is potentially threatening to the situational awareness of pilots and as such, to their safety. Solutions to keep track of the situation are sought, amongst others, in automated tactical decision aids. To what extend will pilots benefit from such systems? Will mission performance increase? What are the disadvantages? To answer these questions an experiment was designed, which will be described in this part of the paper. The experiment can be characterised best as an evaluation by fighter pilots of a threat management support system.

Figure 8. F-16 MLU cockpit

The experiment is performed in the NLR National Simulation Facility (NSF), see figures 4 and 8. This simulator is configured with an F-16 MLU cockpit. Mission profiles and controls used by the pilots during the experimental runs were recorded. Instrumentation and fittings allowed variables such as heartbeat frequency, eye point-of-gaze, pupil size, and eye blink rate to be measured.

Pilots flew through scenarios in which they encountered several threats. The taskload between the scenarios was varied by the amount of surface threats that were implemented in the scenarios. In half of the test runs pilots had to deal with the treats manually, while in the other half an automated system initiated appropriate counter measures by itself.

Afterwards pilot performance, subjective and objective mental workload and the pilot appreciation of the automated threat management system were evaluated. For the experiment, we used the NCMM, mentioned in section 3.4 and further extensively described in chapter 4. Chapter 5 will present the experiment set up and describe the results.

4 NLR Counter Measure Manager (NCMM)

To countermeasure SAMs, the pilot has several options available. Generally, the best course of action is to avoid entering SAM rings, but this cannot always be avoided, especially when pop-up threats are encountered. Depending on the type of threat and its state, the pilot can jam or dispense chaff en flares. Usually, these counter measures are combined with a manoeuvre.

The NCMM agent determines the most effective use of actors to counter detected threats. Such an agent enables co-ordinated counter measures that can not be performed manually using the separate systems [Tempelman 1999], [Eertink 2000]. A schematic representation of the manager's architecture is supplied in figure 9.

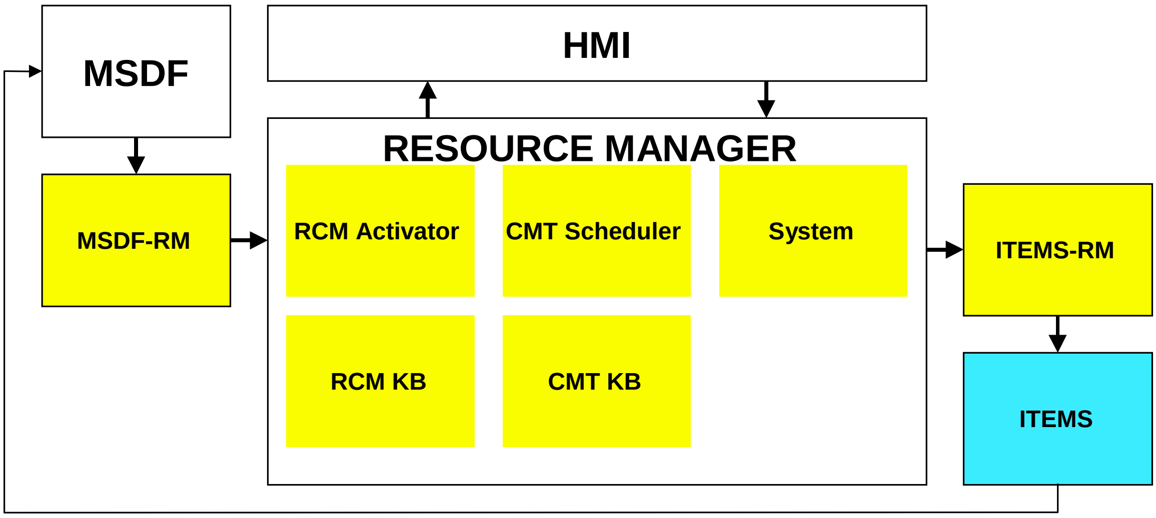


Figure 9. The NCMM in the simulation environment.

The MSDF agent delivers environment data, most notably sensor tracks and threat information, to the resource manager. The resource manager is the core of the NCMM. It consists of two rule-based knowledge bases: the Reflex Counter Measure (RCM) Knowledge Base and the Counter Measure Technique (CMT) Knowledge Base. The first associates sensor tracks directly to single counter measures (e.g., chaff, flare, a jamming technique, a manoeuvre), in situations where immediate action is required. The latter connects threats, i.e., fused sensor tracks, under certain positional conditions to a series of counter measures, after which the dynamically planning CMT Scheduler fits these into the existing counter measure schedule.

An example of the represented CMT knowledge is given in table 1. Rule number 12 (highlighted in the table), for example, represents what can be done to counter a threat of type SAM1 in track (T) mode, which has threat level (lethality) 4 on a scale of 0 to 10. The SAM1 is detected by two sensors, the Radar Warning Receiver (R) and the ALQ (J). With an expected effectiveness of 8 on a similar scale, it can be countered by a combination of Range-Gate Pull-Off (a jamming technique) followed by dispensing 4 bundles of chaff with an interval of 0.2 seconds (4C0.2), if the condition on the threat's position is fulfilled.

The knowledge in the resource manager is highly flexible. It can be adapted easily to include newly constructed counter measure techniques and it can be modified to reflect the availability of other agents in the aircraft in which the NCMM is running.

Various operational modes are available in the NCMM. These determine the availability of assets in various circumstances. For example, it can be necessary to not use jamming counter measures, as the enemy can detect these. Selecting the operational mode 'Run Silent' will then take care of this. Furthermore, the NCMM agent supports system modes, determining the amount of automation of the system. These vary from manual, in which case only advises are given, to fully automatic, in which case all counter measures except manoeuvres are executed automatically and in time. For reasons of pilot convenience, manoeuvres will only be advised.

ID	Threat	Mode	TL	Sensors	Effectiveness	GCMT
1	SAM1	S	3	R	5	OT
CONDITION: None						
# Simple example: SAM1 search radar (low TL) detected by RWR only; Turn to evade the site.						
2	SAM1	S	3	R+J	8	N1S
CONDITION: None						
# As above, only now the site is also detected by the ALQ, so jamming can be used (Noise).						
12	SAM1	T	4	R+J	8	RGPO1C+4C0.2
CONDITION: Threat at (20°<F<60°)∨(300°<F<340°)						
# Sam is tracking the aircraft. Combination of RGPO and chaff is effective, but only at certain azimuth angles						
32	SAM1	L	9	R+J+MA	8	VGPO1
CONDITION: Time Till Intercept≥5s						
# see number 34.						
34	SAM1	L	10	R+J+MA	5	6GturnInto
CONDITION: Time Till Intercept<5s						
# Missile is launched, detected by MAW. Assuming semi-active missile, VGPO can be attempted. If this fails (TTI<5s), perform last ditch manoeuvre						

Table 1. Part of the CMT knowledge base

The NCMM was evaluated and validated in a semi-realistic simulation environment called ITEMS. Various scenarios were flown in various modes. A simple scenario, in which no threats overlap, is shown in figure 10. The flexibility of the manager was demonstrated by running it both in a simulated F-16 and in an Orion P3, the latter having far less counter measure possibilities. The NCMM demonstrated improved effectiveness and efficiency of using countermeasures against threats in a number of multi-threat scenarios, compared to manually threat countering. Advantages are that series of counter measures that require exact timing with respect to each other can be executed automatically, that the NCMM can combine counter measures to counter multiple threats, and that the NCMM can take the effect of a counter measure against a threat to other threats into account in highly complicated situations.

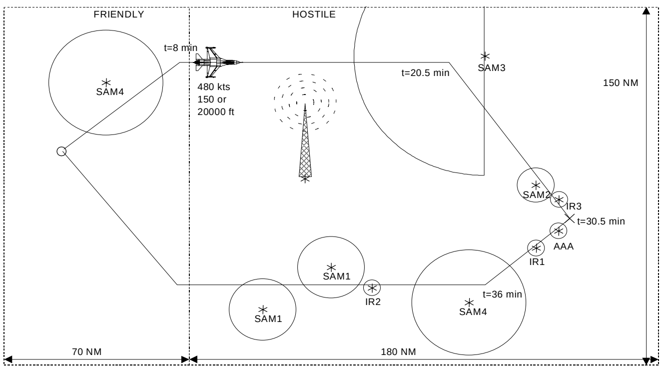


Figure 10. Example scenario for NCMM validation.

5 A threat management support experiment

This chapter describes the experiment set up and the results.

5.1 Experiment Description

The purpose of the current experiment is to demonstrate the advantages and disadvantages of a CA. The experiment will show whether automation about threat management tasks is beneficial to the mission compared to the current situation, in which pilots have to perform these tasks without such support. To define the additional value of the support, the mission performance, the subjectively and objectively measured fatigue and workload of the pilots has beeen investigated. NCMM served as the threat management support system (the CA).

The experiment was designed to answer the following specific questions:

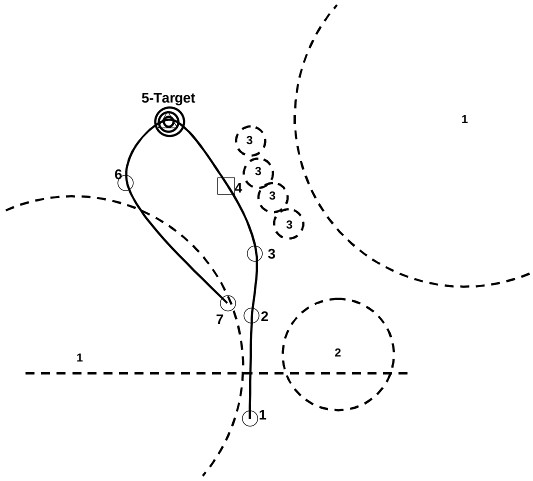
- Does decision support improve pilot performance (fighter performance, mission effectiveness), especially in situations in which a great deal of the pilot's attention is needed for other tasks (high taskload saturation)?
- Will pilots appreciate the tool when they can be convinced that the pilot always remains in control?
- Will the integrated way of information presentation, that is part of the CA interface in the current experiment, aid the pilots in gaining and remaining their situational awareness?
- Will pilots get a better understanding and appreciation of the tool after they are given time to test it thoroughly?
- Will pilots either experience a workload decrease, a performance increase, or a combination of both as a result of the CA?
- The moments with the highest workload are needed here. Heart rate during those moments should be compared between the CA on and the CA off.

Nine operational male F-16 pilots from the Royal Netherlands Airforce participated each for one day in the experiment. The right Multi Function Display (MFD) was reserved entirely for NCMM. Swapping the NCMM page, or removing it from the MFD, was not possible. The pilot was informed about NCMM system mode before the run started.

During half of the runs NCMM operated in the standby mode. In this mode NCMM provides explanatory information about the location and type of the surface threats and the flight path only. In this mode NCMM does provide the same information as what is now available on the current F-16 MLU Multi Function Displays in combination with the Radar Warning Receiver (RWR). The pilot selected and executed the counter measures against the threats manually. He had to actively dispense chaff and flare and select the jamming mode. Manoeuvres had to be executed manually.

During the other half of the runs NCMM operated in the automatic mode. In this mode NCMM decides when to expend chaff and flare and dispenses them automatically. The pilot can dispense additional chaff and/or flare manually in this mode. Also the appropriate jamming modes are selected automatically. In addition, NCMM also advises about appropriate manoeuvring. However, the execution of the manoeuvres has to be done by the pilot.

The pilots' task was to fly six low altitude weapon delivery missions. Each run had the same mission goals but the mission profile was different every time. Pilots were instructed to stay to the assigned flight path as much as possible. They were also asked to fly low altitude, though not too low so that they would not fly below radar coverage. The pilots were recommended to use NCMM advice if they felt that it was tactically sound, but to otherwise execute their own plan. Each scenario consisted of a short flight (duration was about ten to fifteen minutes) in which the subjects encountered a number of threats. During the runs several threats could pop up. Given the nature of NCMM it was decided to use, primarily, surface threats. Pre-planned threats and steer points



were chosen such that the missions that the pilots were flying could well be compared. Pop-up threats always combined to a pre-planned threat in such a way that a logical course of action would follow. An example of a mission with pre-planned threats is given in figure 11. The dashed circles represent the threats with a numbered classification (fictive). The line is the route to be followed, including numbered way points. Way point number five is the target.

Figure 11. Example mission with pre-planned threats.

5.2 Experiment design

In one condition NCMM provided decision support (automatic mode). This condition was compared to a condition in which NCMM provided explanatory information about the threats only (standby mode) but no advice was offered.

The effect of NCMM was investigated both under high task load and low task load conditions. During half of the runs the pilot was flying in a low workload environment. A limited amount of surface threats was present during those runs. During the other half of the runs a high workload environment was presented. In these scenarios more surface threats were present and enemy fighter aircraft could be encountered.

The benefits of NCMM were compared between the two NCMM modes and the two levels of task load. The above means that the pilots had to fly scenarios in four different configurations.

Since pilots had to fly six runs each and because it was undesired that they transferred experience between scenarios, three different mission profiles were developed. The runs were assigned over these profiles and the four experimental conditions. This approach ensured that pilots never flew the same run twice. It also ensured that they flew three runs with NCMM in standby and three in automatic mode and it finally ensured that they flew three runs in a high and three in a low workload condition.

5.3 Measurements and equipment

During the missions, all information that was exchanged between the agents and between the agents and the pilots was logged. Besides, psychophysiological measurements were taken and the pilots were asked to fill out questionnaires at several moments during the day.

In close co-operation with operational experts, simulator events have been valued in terms of performance. Based upon the hypotheses a selection of simulator and NCMM variables was made, in order to be recorded. These comprise amongst others: countermeasures made by NCMM (in automatic mode), countermeasures made by pilot (in stand by mode), mission duration, amount of time spent in search or track of threats, deviations from the flight path, and weapon delivery events.

Heart rate
In addition to the simulator logfiles, other objective indicators of mental workload, namely psychophysiological parameters, were recorded by the Vitaport 1 system. Those comprise the electrocardiogram (ECG) and respiration. ECG was measured with three Ag/AgCl electrodes. One was attached approximately 4 cm. above the jugular notch of the sternum, one at the apex of the heart over the ninth rib, and the ground electrode was placed above the right iliac crest. The ECG was used to determine the Heart Rate (HR) and Heart Rate Variance (HRV). Respiration was measured using a pair of strain gauge transducers around the chest and the abdomen, so that the influences of respiration rate, and speech, on HRV could be filtered out later. During the offline data analysis HR artefact correction was carried out according to a procedure described by [Mulder 1988].

Eye Point-of-Gaze
Eye Point-of-Gaze is the point on a predefined surface were an imaginary line coming straight from the centre of the eye crosses that surface via the lens of the eye. As such this is the central point in the pilot's field of vision. This point was measured by means of an EPOG-recorder called GazeTracker [Mooij 1996]. The duration that a pilot looks at a particular area of interest, is called a "dwell", which was stored in a computer file. In addition to the dwell-times the scanning pattern, the amounts of fixations, the pupil diameter, and eye the blink activity (which permits blink rate, duration, and other measures to be derived) of the pilots' left eye were recorded as indicators of fatigue and mental and visual workload [Harris 1986], [Wilson 1987], [Wilson 1993], [Stern 1994]. The scanning behavior was considered to be an indicator of the pilot's mental state and focus of attention. The commonly accepted assumption was made that if a pilot looks at a particular area of interest he is mentally processing the data that are manifest at that area.

5.4 Results

The pre- and post experiment questionnaires demonstrates that pilot opinion, regarding a number of NCMM related items, had changed after using the NCMM in the experiment.

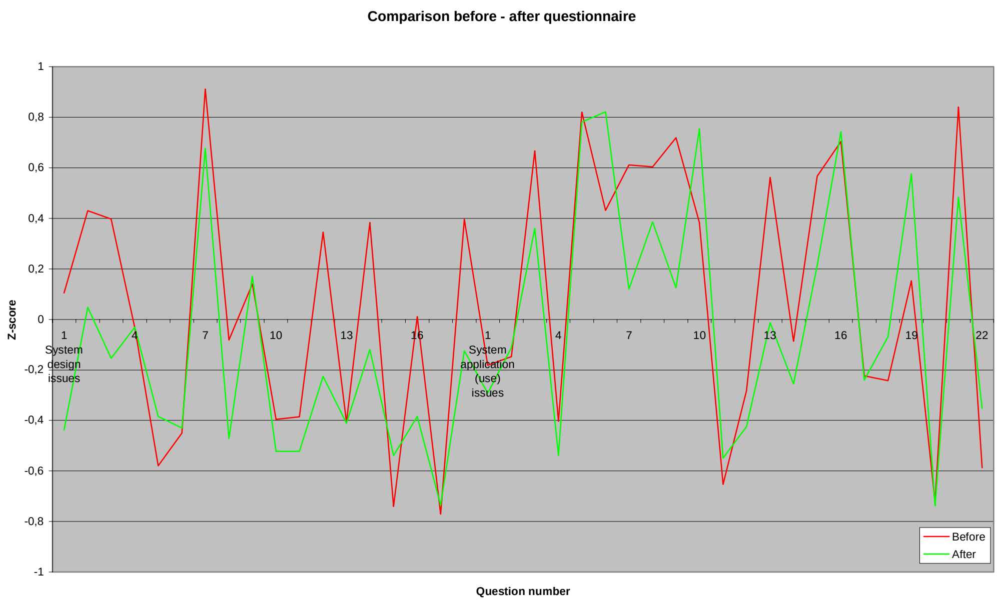


Figure 12. Responses to questionnaires before and after the experiment. Answers were first transferred to Z-scores[1]. After that, the average over all pilots was calculated, and plotted in this figure.

[1] Z scores are standardised scores. They were calculated using the following formula: Z score = (raw score - mean) / standard deviation.

In figure 12, the pilot ratings before and after the experiment are displayed. The left side of the graph shows the answers to the "system design issue" questions. The right half shows the answers to the "system application (use) issues". The red line represents the average of all pilot responses to the pre-experiment questionnaire. The green line represents the average of all pilot responses to the post-experiment questionnaire. Distances between the two lines may be seen as an indication of the "change of mind" of the pilots after using NCMM in the NSF for several hours.

While often the trends of both lines are the same, there are differences as well. Roughly speaking the differences (distances between the two lines) comprise the following issues.

With respect to the system design related questions, it was observed that the pilots were more convinced, after using NCMM, that:

- It performs like a real pilot.
- Integration in the aircraft may be adequate.
- It does not show too much irrelevant/distracting details.
- NCMM is capable of taking pilot personal preferences into account.
- NCMM is sufficiently sensitive to specific mission demands.

The most important results concerning the system application (use) were that pilots, after using NCMM, were more convinced that:

- They have confidence in the system and will as such use it.
- They will not necessarily (eventually) loose EW related skills when using NCMM.
- They will not pay too much attention to NCMM.

Situational Awareness (SA) as rated by the pilots themselves and by an observer is visualized in figure 13

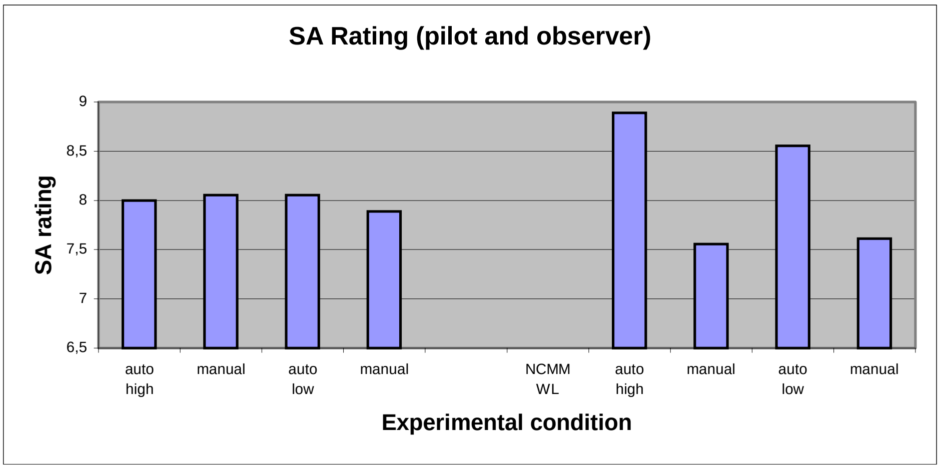


Figure 13. Pilot and observer ratings of pilot situational awareness.

Note that pilots considered their SA at approximately the same level during all four conditions, but that the observer, who was aware of everything that happened in the scenarios (even those things that pilots could never be aware off) rated the pilot SA higher during the missions were NCMM was running in automatic mode.

One of the performance indicators that was monitored was the jamming mode the pilots selected versus the jamming mode that was selected by NCMM. While watching the pilots perform, it already became very likely that pilots frequently forgot to select the appropriate jamming mode, while NCMM selected the right jamming mode as soon as it has identified a new (high priority) threat.

6 Conclusions from the POWER project

With the increase in aircraft speed and on-board technological developments and the increasing complexity of military environment and missions, the workload of the fighter pilot is rapidly increasing. Crew assistant technology is aimed at reducing the pilot's workload through enhanced situational awareness.

The POWER project provided a large scale demonstrator for crew assistant technology. An architecture, based on multi-agent technology has been set up, where different examples of crew assistants have been integrated:

- A profile recognition detects profiles in the assembled picture from the multi-sensor data fusion process.
- A manoeuvre prediction can be used in dogfight situations to predict and anticipate enemy aircraft's manoeuvres.
- NCMM is the NLR Counter Measure Manager to assist the pilot in taking counter measures against ground threats.

The focus of the project has been decision support in operational fighter aircraft scenarios through the integration of AIP and HF aspects in the military cockpit. We have shown the integration of these areas by examining different AIP techniques and their integration in the cockpit. Display design has been carefully taken place to take the HF aspects into account. A step has been made in the quantitative and qualitative effects of on-board decision support functions in an experiment where operational F-16 pilots participated.

We examined the possibilities for real-time and especially any-time reasoning in on-board application. Any-time algorithms provide the possibility to interrupt the reasoning process at any moment thus enabling optimal processor performance and use. Promising techniques are Bayesian Belief Networks and case based reasoning.

Future work will be directed to the maintenance of the architecture provided and to the further integration of agents, both functional and for system control and monitoring. More work needs to be carried out to reasoning with uncertainty. The environment can be used to facility more experiments.

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Future Trends and Developments

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Challanges for the future

The various technical items described during the Lecture Series were covering modern Information Technology applications and achievements in the Situational Awareness and Decision Aids Systems.
The Authors unanimously agreed in suggesting improvements for the future in what follows.

Decision Superiority

Particular emphasis was given by the Authors on the effort in implementing the information gathering, processing, managing and disseminating Systems to improve the Operators capabilities to reach decisions better and faster than before.
This was considered as the capability to reach the *Information Superiority*.
The ever more demanding requirements to exploit the Sensors resources to their full effectiveness and the Information Technologies to their best, in order to provide to the Operators the most successful decision-making capabilities, have introduced the new concept of *Decision Superiority*.
This because the *Information* in itself could be imprecise, sparse or massive and confusing, resulting therefore counterproductive with respect to the time critical decision- making.
Thus, there is the need to use a higher level of Information Technologies capabilities enabling the Operators to reach the best possible *Decisions*.
To do so, the *Decisions* will have to be reached by an ever more integrated mix of *human and machine reasoning*.
This represents the new challenges for the development of the future Decision Aids Systems.

Beyond Awareness

The result of the *Decision Superiority* is a *Beyond Awareness* capability.
This means that the Operators perspective on *Situation Awareness* must be expanded beyond the simple notion of a common operational picture or consistent tactical picture.
There is the need to be aware of what the information means and what to do with it.
In summary the approach can be considered as three levels that build upon one another:

- Acquiring, disseminating and integrating information
- Processing, displaying and understanding information
- Determining how to act on information

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While the first level of capability involves Sensors and other external data to provide the best knowledge of the *Battlespace*, the second level is able to appraise the available information to identify criticalities and to correlate observations in order to create a better understanding of it.
Finally the third and more difficult level relates to support the decision to act.
This corresponds to the *decide and act* capability, the main decision-maker task.
Thus, the challenge for the future is to complement the ability to collect, process and disseminate information with a more accurate capability to use the information.
Areas of Information Technology improvements are seen especially in:

- Artificial Intelligence
- Expert Systems
- Faster-than-real-time Simulation
- Intelligent agents

Battlespace Dominance

The success in achieving the *decide and act* capability will result in more and more complete *Battlespace Dominance*, in line with the always increasing Defense needs.

Human and Machine Integration

The final question is how to use the achieved *Decision Superiority* and *Beyond Awareness* capabilities in the most effective way.
The simplest answer could be to extend and complement the human operator capabilities with those provided by the machine but it is not so easy.
It is necessary to avoid the “man-out-of-the-loop” effect which could lead to unexpected and dangerous uncontrollable results; in the other hand it is often necessary to decide and react so quickly and beyond human capabilities to counteract a situation.
This is a dilemma that is necessary to solve to obtain maximum benefits from today emerging technologies.

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Requirements
Situation representation
Situational awareness
Task analysis
TDA (Tactical Decision Aids)

14. Abstract

Today, the use of decision aids systems for commander and operators in the battlefield area is playing an important role due to the new frequent situation of joint coalition and asymmetric warfare in which the defense forces are involved.

On these occasions, the capability of own forces to have the evolution of the tactical situation in real time is extremely important.

Since combat survival and mission accomplishment depend upon operators performance in the process of decision-making, and the operator performance depends upon the degree of awareness, situation awareness can be seen as a result of a continuous assessment of situation parameters by the operators. This mission critical chain of sub-segment functions is greatly influenced by the nature of the technical systems the operator is leading with.

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