Understanding and Improving Knowledge Transactions in Command and Control

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Abstract

Numerous factors impact the efficient and effective exchange of information and knowledge in modern command and control. One factor in particular is the extent to which those who create and share information and knowledge understand the tasks and information requirements of those who will use the shared information. Efficient and effective information exchange requires that two classes of users, referred to as information consumers and information producers, develop a shared understanding of tasks, resources, and information requirements. This shared understanding serves as a framework for the intricate series of "knowledge transactions" inherent to collaboration, planning, and decision support.

Building on the successes of past research and development programs, researchers and technologists working at the Space and Naval Warfare Systems Center, San Diego, under the sponsorship of the Office of Naval Research (ONR), are exploring the knowledge transaction processes involved during collaboration in a group/team context when these groups are at different echelons of command.

This paper will 1) introduce some of the current work associated with military command and control knowledge transactions, 2) provide examples of real-world knowledge transaction characteristics and limitations, and 3) discuss recent, ongoing, and planned research efforts to better understand and improve such transactions.

Introduction

Military command and control offers varied challenges to the warfighter. For example, complex and interrelated plans must be developed and executed, limited resources must be carefully managed and coordinated, and time-critical high-stakes decisions must be made. To support this, available data and information resources must be quickly and efficiently processed and analyzed, and then formatted and presented to fully support critical decisions. Often, information must be exchanged among individuals and teams working asynchronously at distributed locations. Commonly, information produced and optimized for one person or group, must be used by others with very different tasks and information requirements. New technologies make it possible to transfer information to almost any location; however, these same technologies do not necessarily facilitate the exchange of *relevant* information. Each of these circumstances presents significant cognitive, procedural, or technical challenges to the modern warfighter.

Recent research and development efforts sponsored by the Office of Naval Research (ONR) have focused on the development of technologies, processes, and recommendations using cognitive models of decision making for real-time decision support. These and many other efforts have shared a common thread – the efficient and effective exchange of information and knowledge from one system, group, or individual to another in support of critical decision making. Building on the lessons learned from these efforts, ONR's *Command 21* project, currently being conducted at SPAWAR Systems Center, San Diego, is conducting research and developing tools and business processes that support efficient and effective exchange of information and knowledge – what we refer to as "knowledge transactions" – between senior decision makers and their support staff in military command centers. Efficient and effective knowledge transactions, when facilitated by technologies that support the human process of information exchange, result in decision makers having access to the information they need when they need it, in a format that is intuitive, easily understood and readily applied.

The *Command 21* research uses the context of collaboration and information and knowledge sharing between multiple individuals as a means for improving collaboration as measured by the quantity and quality of information transactions. Our current focus is on a group/team context when these groups are at different echelons of command. The research also investigates various means of supporting knowledge transaction through the enhancement of shared mental models using tools and business rules that help structure information requirements, alert decision makers to important events and changes, and facilitate efficient information exchange behaviors. We argue that the greater the degree of shared understanding, the more likely that complex structures of information, i.e. knowledge, can be explicitly and implicitly shared between those individuals.

Background

In collaborative environments, inefficient information exchange degrades situation awareness and tactical/operational decision-making (Espinosa, Kraut, Lerch, Slaughter,

Herbsleb & Mockus, 2001), which can lead to costly mistakes or delays in time-critical decision making. Information exchange, as it is discussed here, refers to the process of producing information for, or consuming information from, a shared information store. Participants in the information exchange process can be information producers, consumers, or both. As illustrated in Figure 1, poor information exchange involves one or more of the following: 1) producing information irrelevant to consumer needs as shown in the red-shaded area on the left, 2) not producing information relevant to consumer needs as in the blue-shaded area to the right, 3) consuming irrelevant information, and 4) not consuming relevant information.

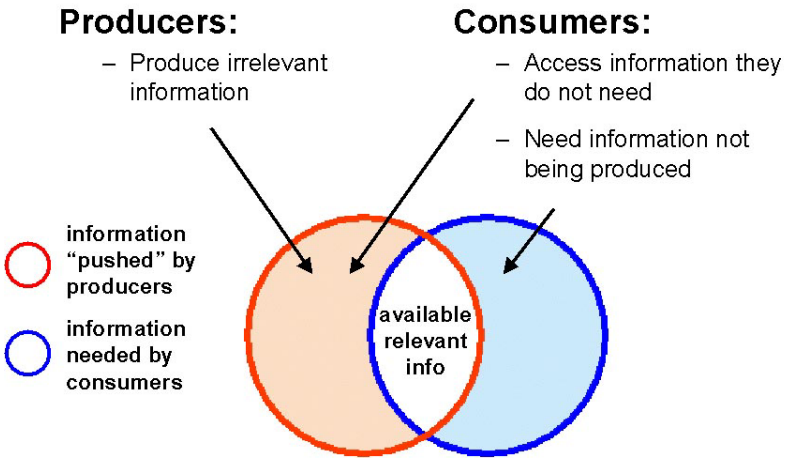

Figure 1. Inefficient and ineffective information exchange.

The production of irrelevant information is *inefficient* in that it wastes the time of both the information consumers and producers. The lack of production of relevant information is *ineffective* in that information consumers cannot access what they need, degrading their situation awareness. In contrast, efficient and effective information exchange is the production and consumption of all relevant information without the production and consumption of irrelevant information as shown on the right in Figure 2. The mechanisms for making information exchange efficient and effective are not yet fully understood.

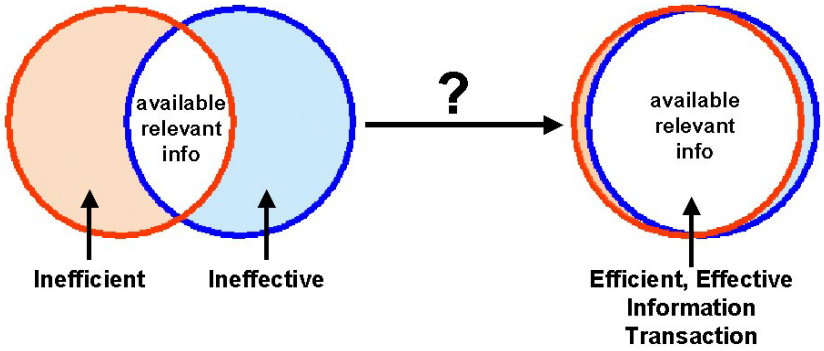

Figure 2. Comparison of information exchange transactions.

Numerous factors are believed to impact the efficient and effective exchange of information and knowledge within a command and control environment. One factor in

particular is the extent to which those who create and share information and knowledge understand the tasks and information requirements of those who will use the shared information. Confirming this is the fact that military decision makers and their staffs consistently state that understanding each other's tasks, intentions, priorities, and information requirements is the first step in effectively working together (Moore & Averett, 1999; Oonk, Rogers, Moore, & Morrison, 2002; Oonk, Smallman, & Moore, 2001; Proctor, St. John, Callan & Holste, 1998; Schermerhorn, Oonk, & Moore, 2003; Smallman, Oonk, & Moore, 2000).

Information consumers and producers can improve individual and team performance and overall situation awareness by developing a shared mental model of tasks, resources, and information requirements (Bolstad & Endsley 1999; Cannon-Bowers, Salas, & Converse, 1993; Mathieu, Goodwin, Heffner, Salas, & Cannon-Bowers, 2000). This understanding – based on the shared mental model – then serves as a framework for the intricate series of "knowledge transactions" inherent to collaboration and decision support.

Past, Ongoing, and Planned Research

Improving tactical decision making under stress. The *Tactical Decision Making Under Stress (TADMUS)* program (Hutchins, 1996) was conducted to apply developments in decision theory and human-system interaction technology to the design of a decision support system for enhancing tactical decision making under the highly complex conditions involved in anti-air warfare in littoral environments. *TADMUS* developed a philosophy of decision support based on Naturalistic Decision-Making theory (Klein, 1992), and produced a number of decision support tools. The *TADMUS* program found that by understanding decision makers' information requirements, and designing systems to match those requirements, significant improvements in situation awareness and significant reductions in decision error could be realized (Hutchins, Morrison & Kelly, 1996). These findings, and the lessons learned from the *TADMUS* efforts, have important implications for the development of tools to facilitate efficient and effective information and knowledge exchange.

Cognitive task analysis (CTA) in support of Knowledge-Web development. Previous interviews with Joint Operation Center (JOC) senior staff (Miller & Klein, 1998; Moore & Averett, 1999) revealed a high priority need for tools to support shared situation awareness and decision-making in the JOC. To address this need, a wall-sized shared display – or "Knowledge Wall" – fusing all information relevant to mission status, was proposed. To help design the initial Knowledge Wall & Knowledge Web, structured interviews were conducted with personnel familiar with JOC operations including command elements from Third Fleet, Carrier Group 1, and Carrier Group 3. Using this interview data, a CTA was conducted (Smallman, Oonk, & Moore, 2000). Fourteen information exchange requirements were distilled from these interviews including:

- Shared situation awareness among JOC users
- The integration of relevant mission status information
- An intuitive graphical interface

- Consistently formatted information
- A tactical focus for the displayed information
- The display of information to supplement tactical data
- The display of mission goals and Commander's Critical Information Requirements (CCIRs)
- The display of summary information provided by "anchor desk" or support staff
- The ability to connect and coordinate or collaborate with others at diverse locations
- A flexible configuration that can easily be changed by users
- The ability to drill-down through displayed information for more detail
- Display of information age and reliability
- Tactical overlays to highlight different types of information

The results of the Knowledge Wall design effort – and of the CTA in particular – highlight the need for the sharing of information within a command center so that personnel have a shared understanding of the situation, and of the tasks, priorities, and resources of those around them.

Decluttering complex information sets. One focus of ONR's ongoing *Basis for Assessment and Geoplot Decluttering* project has been to explore ways to reduce clutter on information displays to help military decision-makers manage their attention and concentrate on the most important or threatening tracks (St. John, Fehér & Morrison, 2002). Researchers have found that cluttered information displays can result in important information being missed, irrelevant information being given too much attention, response times being delayed, and cognitive workload increases. But, simply removing information from cluttered displays means that decision makers have no access to this information if the situation changes and the information is needed. Therefore, studies were conducted to compare methods for making the relevant information stand out on a display while subduing (but not eliminating) information judged less relevant. The findings of this work suggest that similar techniques could be applied to the information exchange environment to help draw attention to relevant information while still providing access to less relevant information.

Identifying individual components of knowledge transactions. In 2002, the *Command 21* project worked to identify individual transaction components in support of a new model of information transaction (Oonk, Schermerhorn, Glaser, & Manes, in press). Researchers looked at identifying specific exchange behaviors and the effect that these behaviors and the participants' shared task awareness had on situational awareness. *Command 21* researchers found that participants exhibited different exchange behaviors as a function of whether they believed the individuals they communicated with shared a task model with them or not. Further, they found that under some circumstances, certain exchange behaviors were correlated with improved situation awareness. The results of this research effort suggest that the initial information exchange model is accurate at predicting the relationships between the components of information exchange – but only early in the exchange process. These same results suggest that the relationships between the components of information exchange change as content in the information space

becomes more fine-tuned and participants to the exchange process develop situation awareness. This finding – if verified in follow-on research – has important implications. It suggests that as individuals' and teams' shared task models evolve, so too must their information exchange behaviors, and the business rules and technologies that support their exchange of information must accommodate this.

Providing just enough context. Previous cognitive task analyses and evaluations of collaboration tool use in distributed multi-echelon environments have indicated that producers often do not understand the information requirements of the consumers with whom they share information. Another observed problem common in this type of multi-consumer context is that consumers are often forced to access and use information products tailored for other consumers performing different tasks. These problems often lead to inefficient and ineffective information exchange (see Figure 1). One of the principle goals of the on-going research, then, is to identify what constitutes an appropriate context in terms of both type and quantity of shared information.

Currently, the *Command 21* project is conducting research that examines methods of communicating information requirements to producers for specific categories of information consumers. In a series of experiments, we are comparing the performance of producers in a multi-echelon, multi-consumer information exchange environment. Four different methods of displaying consumer information requirements to information producers are being compared. The information is of three types: 1) general context regarding what the consumer is interested in; 2) more specific information about what the consumer's tasks are; and 3) a specific list of information needed by the consumer.

Given that these three classes of information generally build on one another, we have created four information context conditions. In condition 1, producers are simply provided information describing the mission (general context) being performed by the prospective consumers. In condition 2, producers are provided information about the consumers' mission plus the consumer's task (shared task awareness). In condition 3, producers are provided information regarding the mission plus a list of content needs (explicit information requirements). Finally, in condition 4, all three types of information about prospective consumers are provided, (context and task awareness and explicit information). Performance in these experiments is based on the information products shared by participants. The relevance of the shared information products under the four conditions are being compared to assessments by military subject matter experts (SMEs). A follow-on study will look at how the sharing of information changes when multiple consumers – each with different tasks and information requirements – are being supported by producers simultaneously. Results of these experiments – to be published in mid-2003 – will allow us to determine how much context should be communicated to information producers to facilitate efficient and effective information exchange, and provide recommendations for tools and business rules to support such exchanges.

Additional research… Follow-on studies, based on the results of ongoing *Command 21* experiments, will examine information transaction behaviors in more complex and

dynamic, realistic environments. In particular, we plan to examine the effects of feedback and change alerting when integrated with the display of consumer information requirements. A larger-scale experiment examining information exchange behaviors, using teams of SMEs as participants, will also be conducted later in 2003. This research, which will be done at the Naval Post Graduate School in Monterey, CA, will be conducted in collaboration with members of other ONR funded projects including *Adaptive Architectures for Command and Control (A2C2)* and *Sentinel* and should lead to improved models of information exchange and decision making.

Summary

The projects summarized in this paper share three common themes. First, that by understanding how people think and act in command and control environments, we can better support their cognitive processes, thereby improving performance and reducing error. Second, that the more people share an understanding of each others' tasks, resources, and information requirements, the better they can support each other. And finally, that the efficient and effective exchange of information is a fundamental part of the command and control process, and a research paradigm is required to assess how effectively complex information is being transacted in an operational environment.

These projects, and others like them, also help to highlight the importance of maintaining strong ties between laboratory-based, theoretical research and very real, operationally relevant problems. In each case, the research conducted was done to address specific issues identified as problems in Navy operations. At the same time, the approaches taken to address the issues were based on sound scientific principles and a growing understanding of human cognition and collaboration.

As we learn more about the way in which people exchange information, develop shared mental models, work together as teams, and perform complex cognitive tasks, we will be better able to improve military command and control processes and the technologies that support them.

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Command and Control Domain

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Common tasks:

- Gather, process, analyze information
- Develop and maintain Situation Awareness
- Develop, execute, and monitor complex & interrelated plans
- Manage / coordinate resources
- Make high-stakes / time-critical decisions
- Communicate / disseminate / coordinate

Complicating factors:

- Often don't have / can't get all needed information
- Available information sometimes conflicting or ambiguous
- Often must collaborate with others on tasks
- Often must provide information to others / use others' information to complete tasks
- Tasks / efforts are often distributed; may be synchronous or asynchronous

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It's all about information exchange…

Command and Control personnel must gather and use information from others

- **People or systems**

Command and Control personnel must convey information to others

- **Plans**
- **Intentions**
- **Orders / Decisions**
- **Information for use by others**

We refer to these exchanges of complex, structured information (specifically, *value-added information*) as "*Knowledge Transactions*"

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Relevant Lessons Learned from Previous Efforts

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Tactical Decision Making Under Stress (TADMUS)

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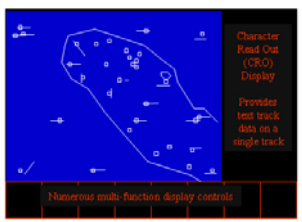
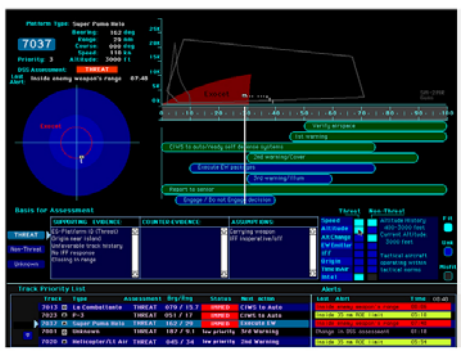
Research efforts conducted to extend and apply developments in decision theory, HCI, and training to support time-critical, high-stakes tactical decision making.

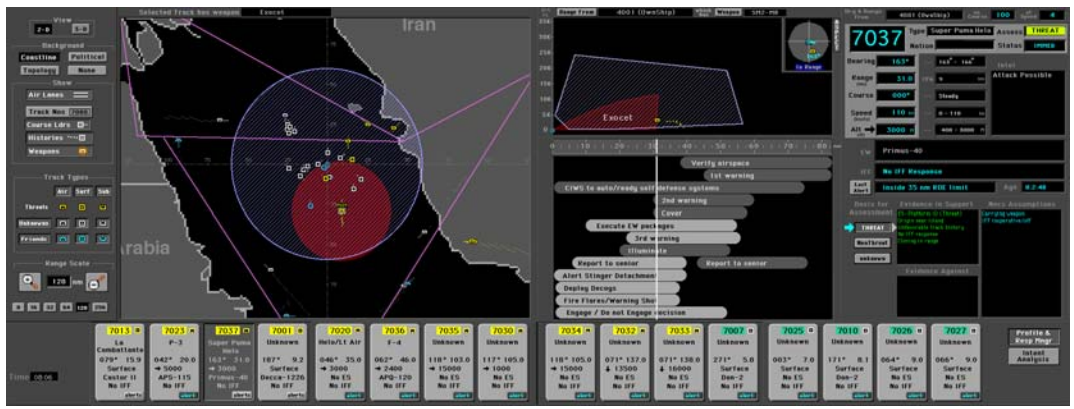
- **Based on Naturalistic Decision Making**
- **Tools introduced new HCI concepts and methods**
- **Validated in realistic CIC team environments**

Lessons Learned: **By designing systems based on an understanding of decision makers' cognitive processes and information requirements we can achieve:**

- **Significant *improvements in Situation Awareness***
- **Significant *reductions in decision error***







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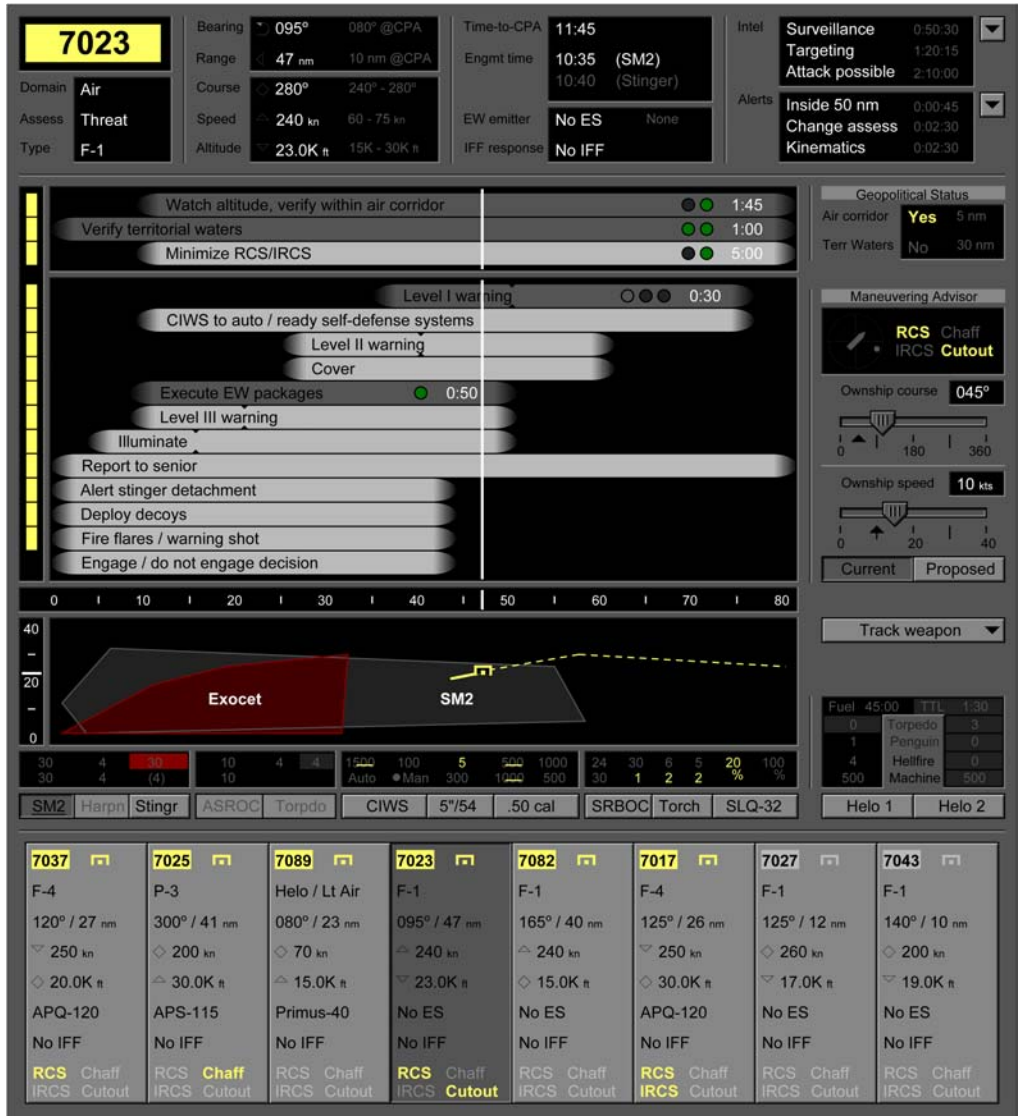
Response Planner & Manager

Design effort to extend TADMUS concepts and develop interface to facilitate response / action management in time-critical tactical decision making situations.

Lessons Learned: **Experts have very different information requirements and decision support needs.**

- **Varies with responsibilities and assigned tasks**
- **One data set / design does not meet the needs of all users**



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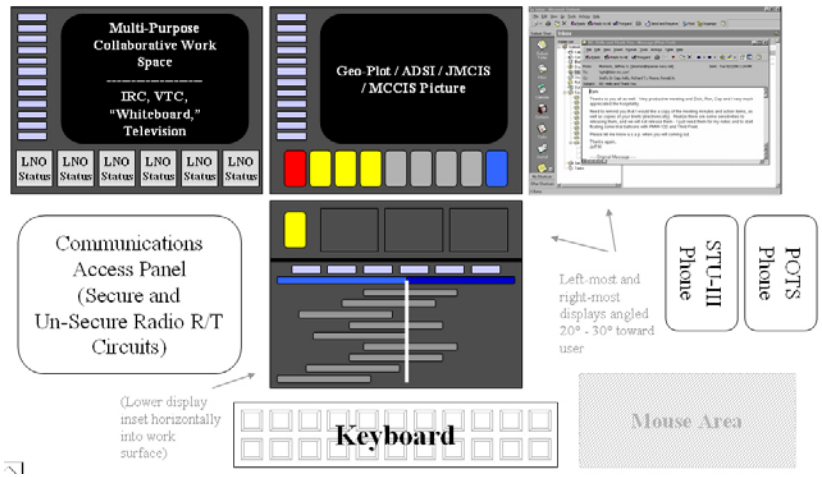
Decision-Centered Design

Project to design next-generation Command Centers and information systems using a decision-centered / user-centered approach

Lessons Learned: **Clear requirements emerge :**

- **Users need "value added" information vice raw data**
- **Users need help managing / using huge amount of data of varying relevance / validity**
- **Regular "information disconnects" occur between peers and other echelons**
- **Different "customers" need different levels of detail / fidelity / depth of information**



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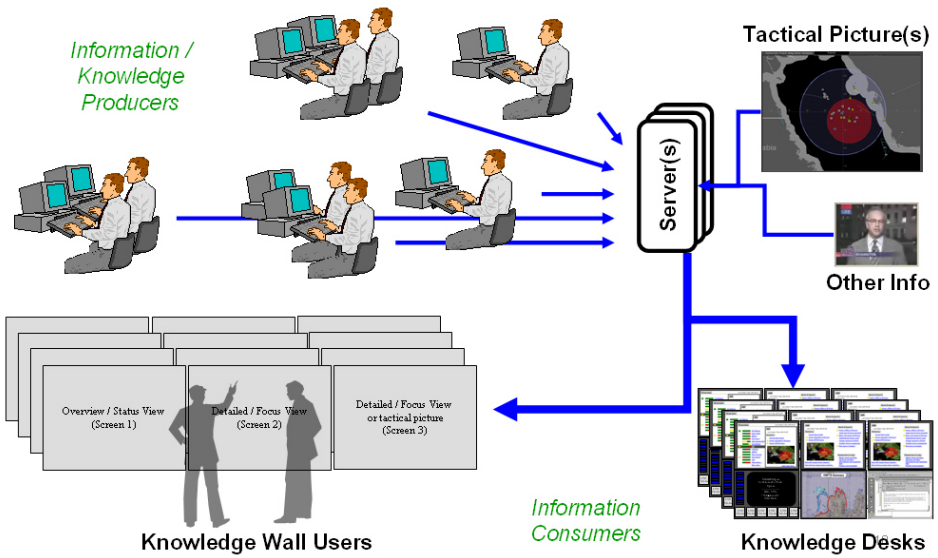
Command 21 (previous years)

Research and development efforts to extend and apply a concept known as "Knowledge Web" to CJTF-level knowledge management.

- **Concept of Operations and Business Rules**
- **Information production, management, and display tools**



Lessons Learned: **Use at Global 2000 and 2001 war games confirmed:**

- **K-Web use significantly increased speed of command and shared SA**
- **K-Web use reduced / eliminated need for traditional briefs / meetings**
- **Cross-echelon and cross-function linking and use is an important and much used aspect of the Knowledge Web concept**
- **When displays optimized for one type of user, was found less useful for others…**

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Command 21 (previous years)

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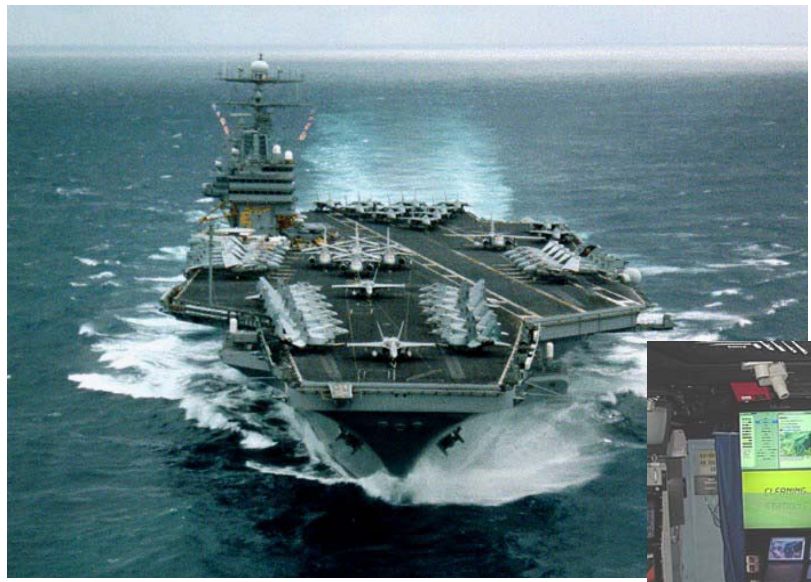
Global 2000 & 2001 Knowledge Walls



K-Web concepts, tools, and technologies validated in war gaming and at-sea use.

- **Carrier Group Three / USS Carl Vinson used K-Web and K-Wall derivative during Operation Enduring Freedom.**
- **14 Functional areas - 500+ Unique Users / Day**

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Evolution of Data to Information to Knowledge: METOC Example

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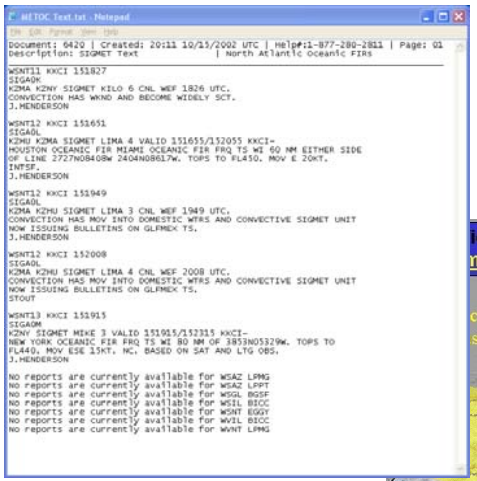
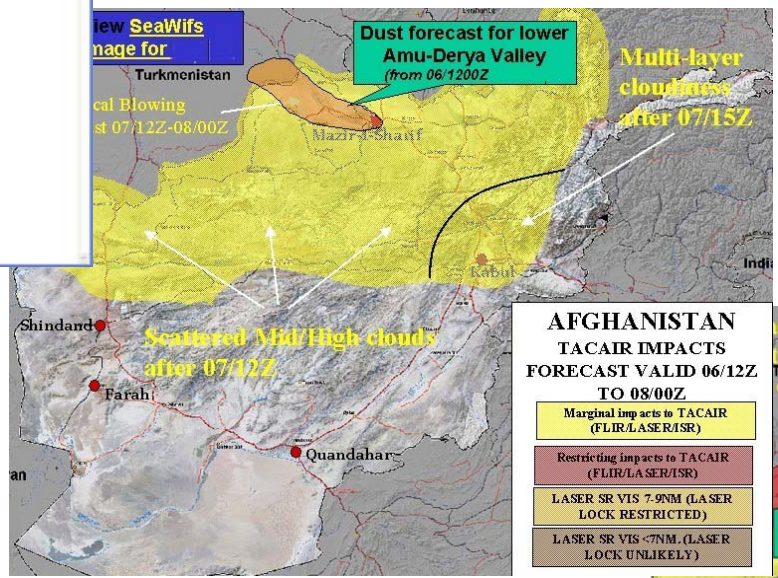
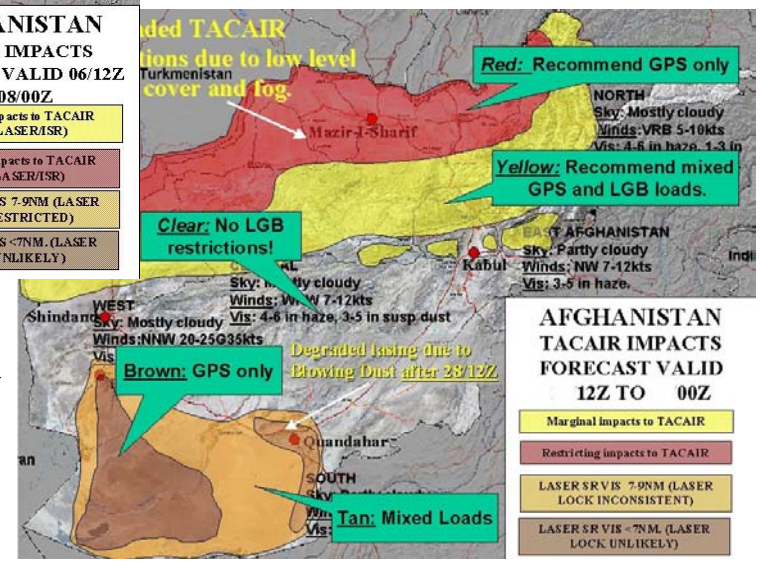


Data: Text-based weather product



Information: raw and semi-processed data represented graphically



Knowledge: weather data and info translated into usable, understandable *Knowledge* of value to planners and pilots

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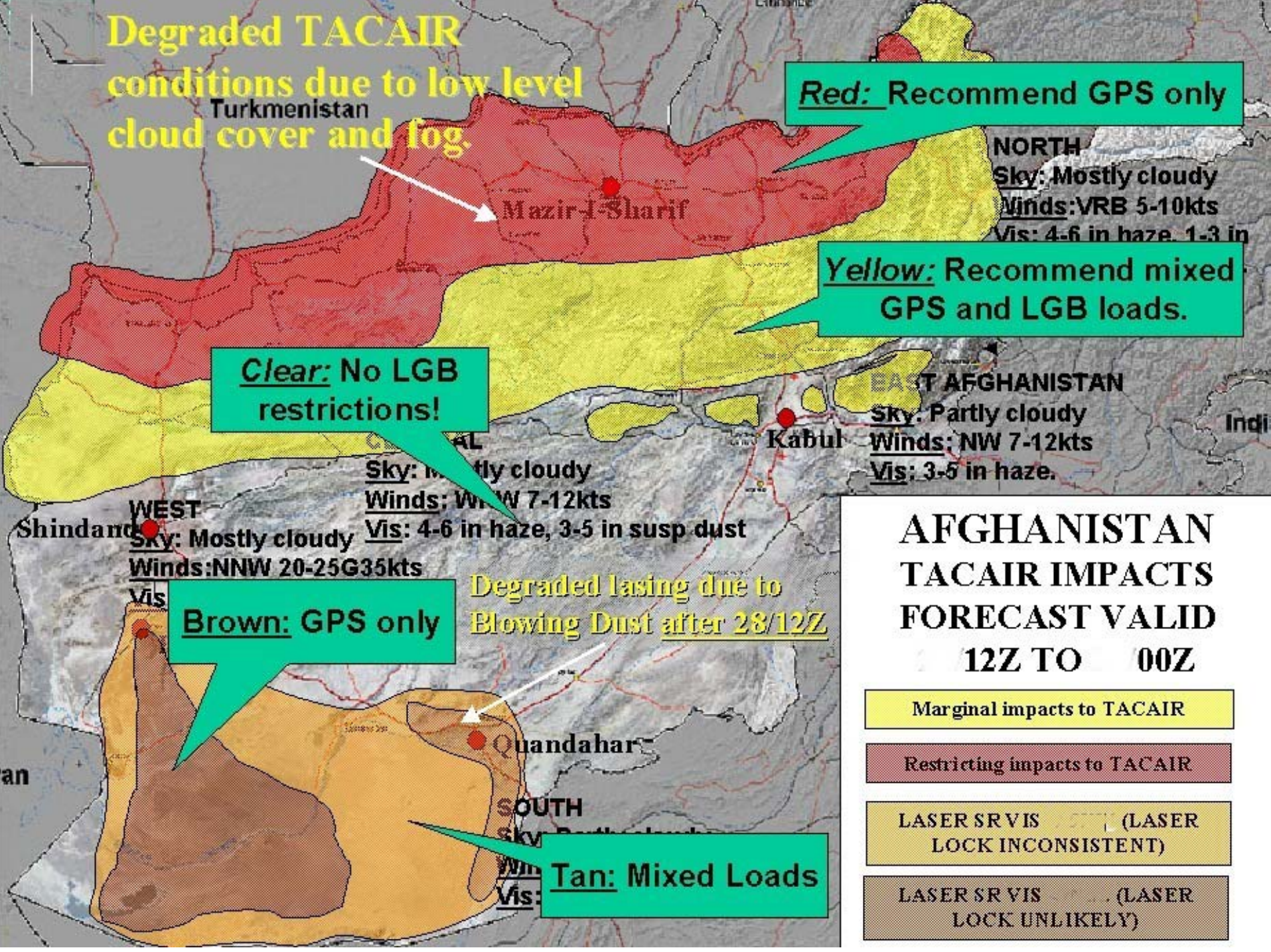

Degraded TACAIR conditions due to low level cloud cover and fog.
Turkmenistan
Mazir-I-Sharif
Red: Recommend GPS only
NORTH
Sky: Mostly cloudy
Winds:VRB 5-10kts
Vis: 4-6 in haze, 1-3 in
Yellow: Recommend mixed GPS and LGB loads.
Clear: No LGB restrictions!
T AFGHANISTAN
Sky: Partly cloudy
Winds: NW 7-12kts
Vis: 3-5 in haze.
Kabul
Indi
Sky: tly cloudy
Winds: W W 7-12kts
Vis: 4-6 in haze, 3-5 in susp dust
WEST
Shindand
Sky: Mostly cloudy
Winds:NNW 20-25G35kts
Vis
Brown: GPS only
Degraded lasing due to Blowing Dust after 28/12Z
Quandahar
SOUTH
Vis:
Tan: Mixed Loads
AFGHANISTAN
TACAIR IMPACTS
FORECAST VALID
12Z TO 00Z
Marginal impacts to TACAIR
Restricting impacts to TACAIR
LASER SR VIS (LASER LOCK INCONSISTENT)
LASER SR VIS (LASER LOCK UNLIKELY)

Knowledge Web Technologies Future Naval Capabilities

SPAWAR Systems Center San Diego

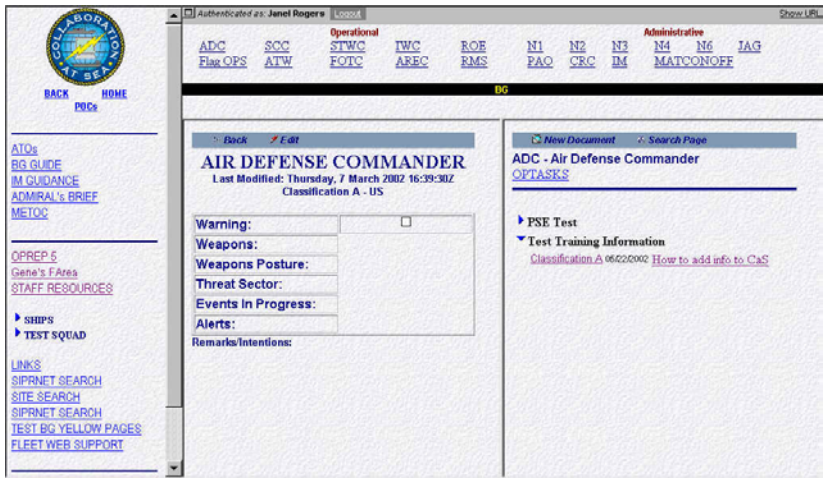
Pacific Science & Engineering

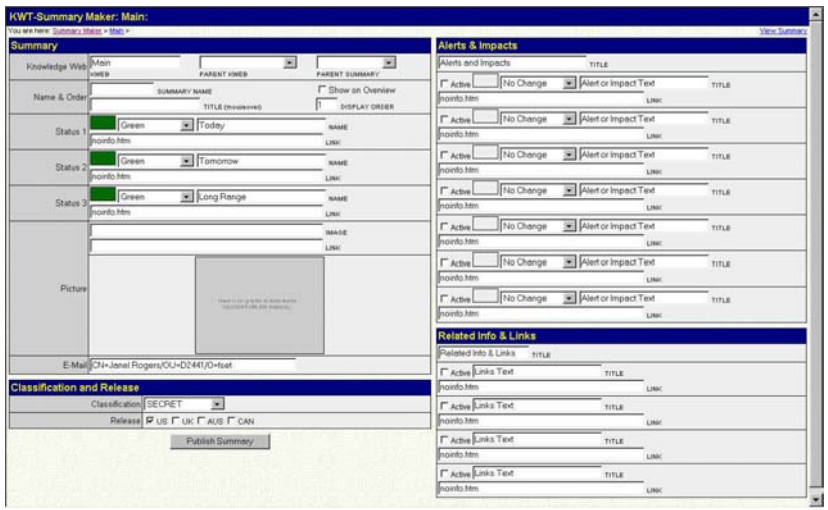
Development and transition efforts to quickly deploy K-Web concepts and technologies to fleet users.

- **K-Webs used in support of Operation Iraqi Freedom**

Lessons Learned: **Wider-scale fleet use reveals:**

- **Users configure, format, and use K-Webs very differently depending on user group and intended audience**
- **Differences can cause confusion among consumers**
- **Bandwidth issues highlight need to focus / filter information to consumers**





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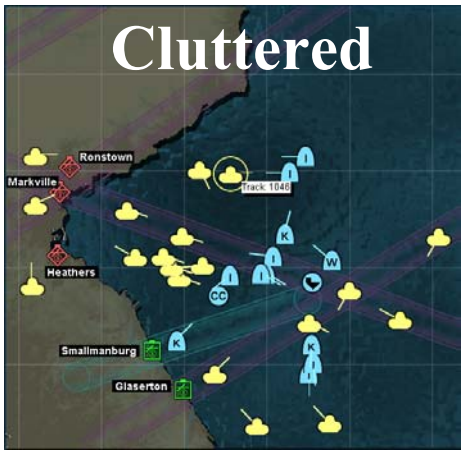
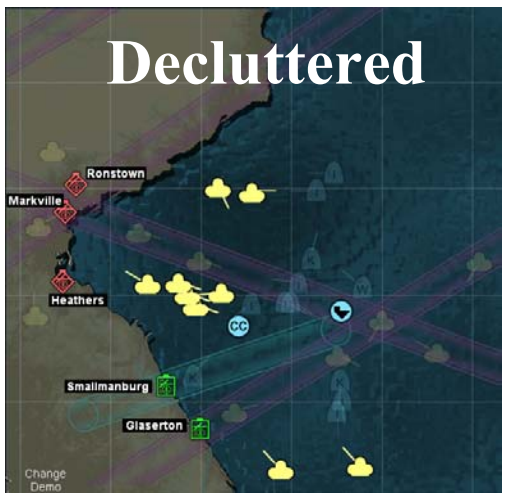
Basis for Assessment / DeClutter





Research conducted to develop context-sensitive models to aid in rapid assessment of tracks, combine with technologies to declutter displays.

- **Based on Naturalistic Decision Making and Marshall's Hybrid Schema DM model**
- **Research exploring new HCI concepts and methods**
- **Concepts validated; improved response times and SA, decreased workload**

Lessons Learned: **Powerful concept and emerging technologies; concepts and techniques might be applied to other information domains (non-tactical displays) to declutter complex information sets (i.e., the Web).**

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Present Focus of Command 21 Project

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Ever-growing Requirement for Information vice Data!

Military Command Centers:

- Research conducted, lessons learned, and evolving needs of Navy have revealed requirement for tools to support:
  - » Improved Situation Awareness / Assessment
    - Perception of Data Patterns
    - Alerting / Attention Management
    - Memory augmentation for Dynamic Events
    - Situation-based Data Fusion
  - » Dynamic, synchronous and asynchronous collaboration
    - Distributed Cognition
    - Adaptive information flow and team structure
  - » Adaptive, real-time resource and action management and planning support

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Context is Key!

- **Tactical data (multiple views if possible!)**
  - **Map-based and highly graphical views / context**
- **Mission Summaries and Commander's Intent**
- **Real-time info! (or close to it)**
- **Alerts / Advisories / Recommendations**
  - **What isn't working according to plan? & What do we do to fix it?**
- **Impacts & Indications**
  - **"X" happened; how does it affect everything else?**
- **Plans (and alternate COAs)**
  - **Response & Timeline Management**
- **Effects Summaries**
  - **Various formats preferred**
- **Asset / Resource Management**
- **Collaboration Tools (including VTC)**

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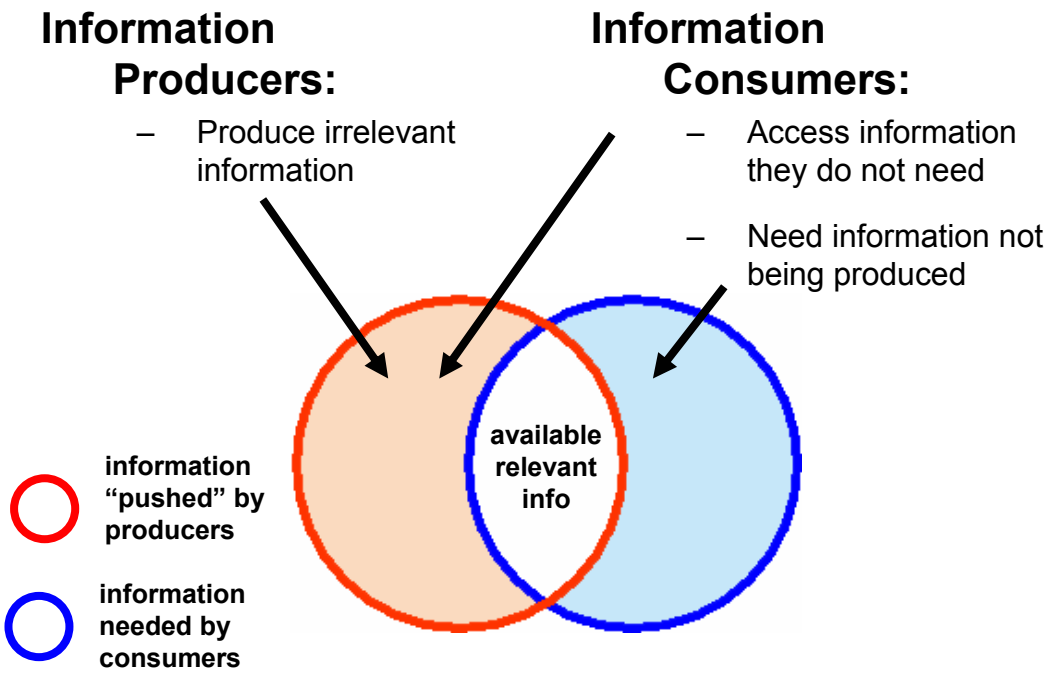
Operational Problem

Ineffective and inefficient information exchange

- **Ineffective: Decision makers aren't getting the information they need – incomplete picture, degraded SA**
- **Inefficient: Decision makers are getting information they don't need – increased workload**
- **Both may lead to suboptimal decision making**



2 (of many) reasons:

- **Information producers often don't understand the decision maker's information requirements and intent**
- **Decision makers accessing information tailored to another decision maker's task and not necessarily their own (esp. in multi-echelon environments)**

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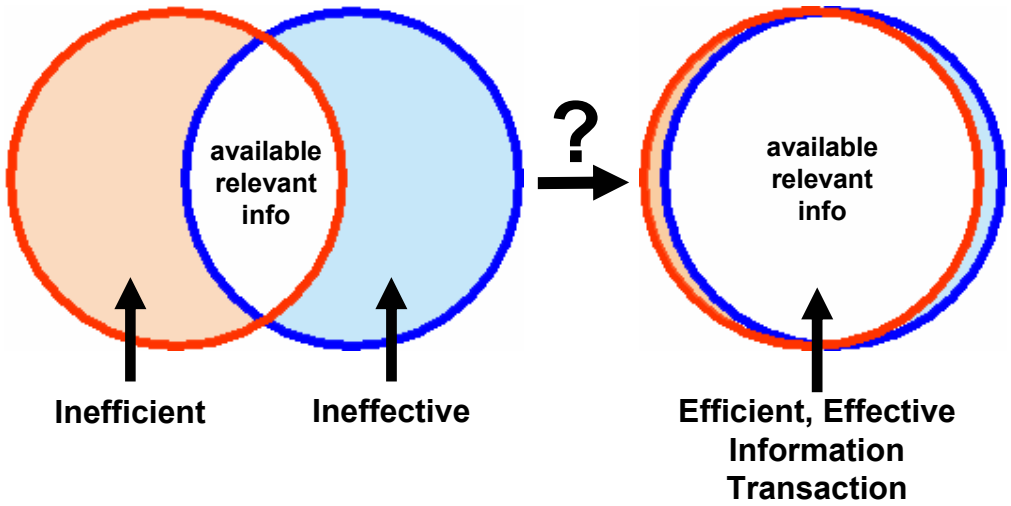
The Challenge…



information "pushed" by producers

information needed by consumers

How do we increase the availability of *relevant* information?

- The information producer must understand the information requirements of the consumer(s).
  - Consumers & Producers must have a shared mental model including factors such as: Tasks, Objectives, Roles and Situation Awareness.
  - Content must be produced that will support different levels of abstraction.
- Consumers need tools to help them tailor the information presented to what is needed in the current mission context.

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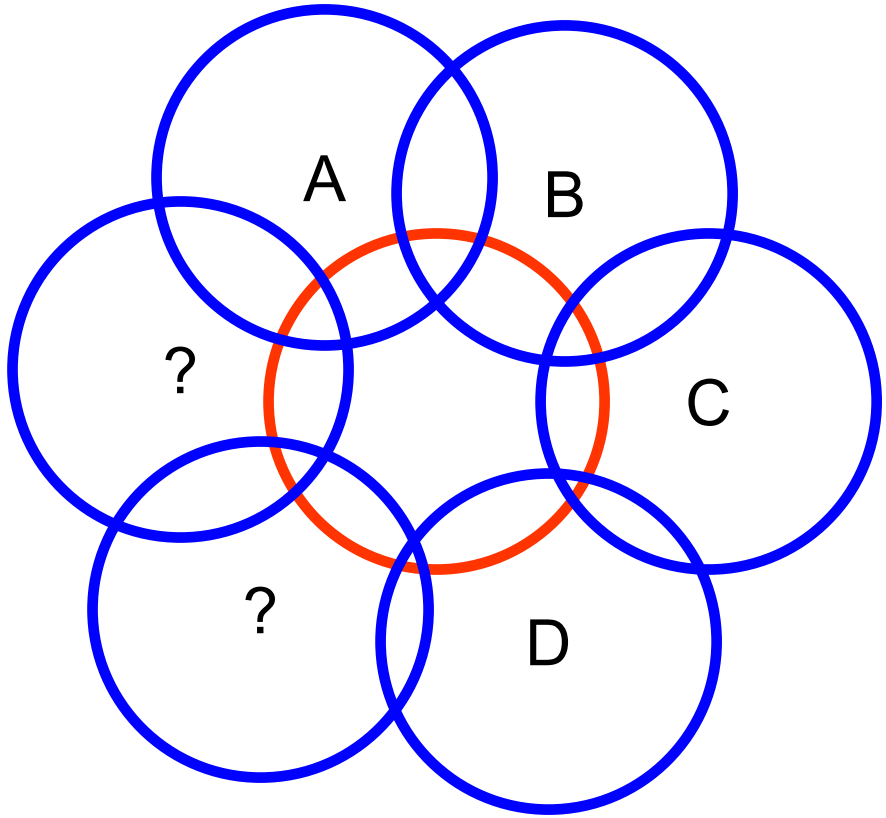
The solution isn't as simple as it might seem…

There are usually many potential consumers… (some known – some not)

Decision makers at different echelons have different goals, tasks, information requirements. Fleet users have indicated the need for *customized* information.*

- **"One glove does not fit all – there needs to be tailorable information"**
- **"So many viewers….Who do you create content for?"**
- **"How do you….tailor information for different [decision makers]?"**



information "pushed" by producers

information needed by consumers

***quotes taken from K-web cognitive task analysis, Global 2000 and Global 2001 War Games, interviews with Carl Vinson K-Web users following Operation Enduring Freedom**

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The Challenge…

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Develop models of how people can efficiently exchange information in at-sea / in-the-field environments.

Build tools using these models that facilitate efficient and effective Knowledge Transactions.

Measures of Effectiveness:

- **Reduce production of unneeded information**
- **Reduce consumers' need to filter out irrelevant / unneeded information**
- **Reduce workload on producers and consumers (or at least, do not increase workloads)**
- **Demonstrate that system can meet the needs of many different consumers - each with their own requirements**

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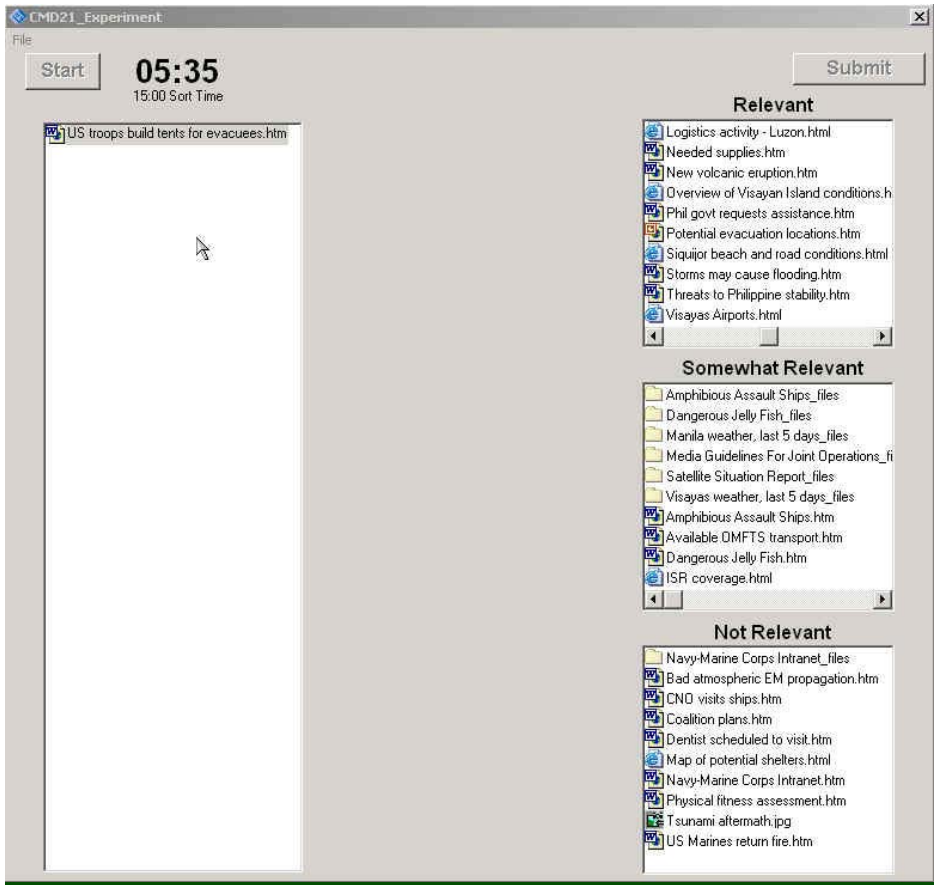
Command 21 (current year)

Ongoing research to determine what factors support efficient and effective information exchange in multi-echelon environments

- **Compares / establishes impact on Knowledge Transactions of sharing Mission, Task, and Information Requirements among distributed, multi-echelon team**
- **Work to be validated at Naval Postgraduate School and at next JFMCC war game at the Naval War College**



Experiment sorting interface

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Command 21 – Initial Findings

Overall, results suggest that:

- **Sharing [Mission + Task] and [Mission + Task + Information Requirements] supported the best performance.**
  - » **In other words, knowing how the consumer is going to use the information provided to them is useful to producer.**
- **Sharing [Mission + Task] most helped producers decide what *to* provide.**
- **Sharing [Mission + Task + Information Requirements] most helped them decide what *not* to provide.**
- **Sharing [Task + Information Requirements] helped producers decide what *to* provide; had little effect on what *not* to provide.**

Results being used to develop a "Context Interface" summarizing Mission, Task, and Information Requirements to help consumers and producers achieve a shared understanding

- **Interface to be demonstrated at NPS this summer/fall**

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Future Areas of Research

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- Advanced structure / templates to facilitate rapid & consistent information production and exchange, and "story building"
- Accommodating the needs of different users at different echelons of command
- Knowledge Management of large stores of information and Knowledge Representation of fused, processed, filtered information
- Representing change and implications within a store of information
- Agents to off-load user of time-consuming knowledge management "administrative" tasks
- Advanced, web-based change awareness and status alerting technologies
- Advanced visualizations of information space to facilitate navigation & assimilation
- Agents to tailor content to different classes of users and afford improved Bandwidth Management
- Tools to facilitate integration of non-tactical and tactical data systems (integrated context)

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Summary

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- **The key to improved Command and Control is the efficient and effective exchange of information – especially value-added knowledge.**
  - **Context is critical**
  - **Knowledge of Content Consumers is vital in effective exchange – particularly with distributed, asynchronous collaboration.**
- **Lessons learned from past, current, and future research are helping us facilitate such exchanges – in the form of improved Knowledge Transactions.**
- **Improved Knowledge Transactions result in users having the right information, when they need it, in a form that is intuitive, easily understood, and readily applied.**

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Pacific Science & Engineering

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