2006 CCRTS

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Decision-Centered Command and Control:

Designing Large Scale Decision Support Environments to Enable Effective Team Decision Making

Topics: C2 Concepts and Organizations; C2 Analysis; Cognitive Domain Issues

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ABSTRACT

Across a variety of work domains, five unique requirements have emerged for achieving highly effective multi-human plus decision support system teams (Billings, 1996; Woods and Sarter, 2000; Woods and Cook, 2003; Elm et al., 2005). Discovered while focused on designing effective decision support systems, these generic support requirements apply to cognitive work by any cognitive agent or any set of cognitive agents, including teams of people and machine agents in a Command and Control (C2) Center. These five requirements discussed in this paper are Observability, Directability, Directed Attention, Resilience, and Teamwork with Agents. This paper will include a generic description of a large scale decision support environment design concept. While the current state of the practice tends to focus on technology upgrades without explicit support for decision-making, this design effort utilized unique design features that resulted from the mission of satisfying these five requirements. This approach influenced the command team organization, the collaboration role of group displays, the attention-direction role of specialized group displays, and the need for coordination between individual workstations and group displays. All of these design concepts are expected to have a significant impact on team decision making effectiveness within the C2 center.

INTRODUCTION

The need for the development of Command and Control (C2) Centers is directly associated with the relative complexity and amount of the decisions contained in a domain. If the goals and required cognitive work of a domain could be managed by one human, the designer would only need to design a single workstation for that single user. Complex C2 domains such as strategy and plans divisions, tactical onboard naval operations centers, and emergency crisis management, dictate the need for a multi-human, multi-agent decision making team to handle the numerous goals within a domain.

The intent of building a decision support environment (i.e. The Air Force's Air Operations Center, Tactical Operations Center) is to contain this multi-human team in a co-location physical space, providing personal access to corresponding decision makers and information resources. This design choice carries the incorrect assumption that because of the proximity of the associated decision makers, coordination and collaboration will occur naturally.

To support the need for effective team decision making, a technologist's solution for the design of the physical space is to place several large panel displays across available surface areas within the room – ready to display any and all data feeds that are available to that team. By installing technology for the sake of newer technology, a technologist would claim that "they put the large scale display on the wall so that everyone can see" and since everyone can see, they must be getting the support they need.

Cognitive Systems Engineering (CSE) asks "In what way do we (as designers) provide decision support *with* the display that we (the decision makers) can all see." Dedicated design for decision support is needed, not only for an individual's decisions on a single display, but across large group displays for coordination and collaboration to achieve effective team decision making in a Command and Control environment.

BACKGROUND

One of the goals of Cognitive Systems Engineering (CSE) is to better understand Joint Cognitive Systems (JCS), that is, the teaming of human agents plus technology, in order to improve overall work performance. Related work from the CSE community has identified the existence of five unique requirements for achieving highly effective multi-human plus decision support system teams (Billings, 1996; Woods and Sarter, 2000; Woods and Cook, 2003; Elm et al., 2005). The discovery of these requirements resulted from CSE research focused on determining how technology can best be used to support effective performance of practitioners in context. CSE seeks to identify what would be useful with respect to new technology and how the technology can be applied in such a way as to improve effectiveness and to avoid undesirable side effects. In essence, CSE is focused on finding affordances that allow the technology to be used by the agents to satisfy their goals.

This approach follows from the finding that the properties of artifacts shape cognition and collaboration, which guide behavior – the Representation Effect (Norman, 1993). Thus, how technology is structured (i.e., its mechanisms for interaction with the operator)

influences the cognitive work that needs to be accomplished, either improving or degrading performance. The Representation Effect summarizes a widespread psychological result that the content and context of a problem can radically alter a decision-maker's responses.

Research into the Representation Effect has found that the relationship (i.e., mapping) between (a) the mechanisms for interaction established by a particular visualization or interface and (b) the constraints and relationships of the work domain, itself, is fundamental to the technology's effectiveness. Without an explicit specification of this mapping, it is impossible to determine if the mechanisms for interaction are supporting operator agent's needs as intended or making the "supported" task more difficult (Zhang, 1997).

The five unique support requirements that have emerged as critical to capturing what it means to provide affordances for work in a JCS should be considered the main support requirements for any new technology. This is especially true for decision-support environments like C2 Centers, Operations Rooms, and Emergency Crisis Management. The five requirements that need to be addressed to support cognitive work by any cognitive agent or any set of cognitive agents, including teams of people and machine agents, are:

- **Observability** – the ability to form insights into a process (either a process in the work domain or in the automation), based on feedback received. Observability overcomes the 'keyhole' effect and allows the practitioner to see sequences and evolution over time, future activities and contingencies, and the patterns and relationships in a process.
- **Directability** – the ability to direct/redirect resources, activities, and priorities as situations change and escalate. Directability allows the practitioner to effectively control the processes in response to (or in anticipation of) changes in the environment.
- **Teamwork with agents** – the ability to coordinate and synchronize activity across agents. This defines the type of coordination (e.g., seeding, reminding, critiquing) between agents. Teamwork with agents allows the practitioner to effectively re-direct agent resources as situations change.
- **Directed attention** – the ability to re-orient focus in a changing world. This includes issues like tracking others' focus of attention and the ease with which they are interrupted. Directed attention allows the human-system team to work in a coordinated manner, resulting in increased effectiveness.
- **Resilience** – the ability to anticipate and adapt to surprise and error. This includes issues such as failure-sensitive strategies, exploring outside the current boundaries or priorities, overcoming the brittleness of automation, and maintaining peripheral awareness to maintain flexibility.

Working to meet these support requirements can be seen as a means to manage the complexities of C2 Center designs so that its overall decision effectiveness is improved. Designing a decision support environment to these requirements helps designers avoid being trapped into technology stove pipes or local coping mechanisms such as

oversimplification tendencies, while trying to adjudicate competing system and support demands.

From a CSE design perspective, the goal is to not only address these support requirements, but also to support the cognitive work of the decision-making within the JCS. Woods (1991) has called this need to explicitly incorporate the functional relationships and cognitive demands of the domain in the interaction mechanisms within the JCS, the 'Mapping Principle.' The Mapping Principle means that one cannot understand information displays in terms of purely visual characteristics, the syntax, but that it must also include an understanding of the decision-making requirements, the semantics. Woods & Roth (1988) state that, "in analogical representation the structure and behavior of the representation (symbol) relates to the structure and behavior of what is represented (referent)."

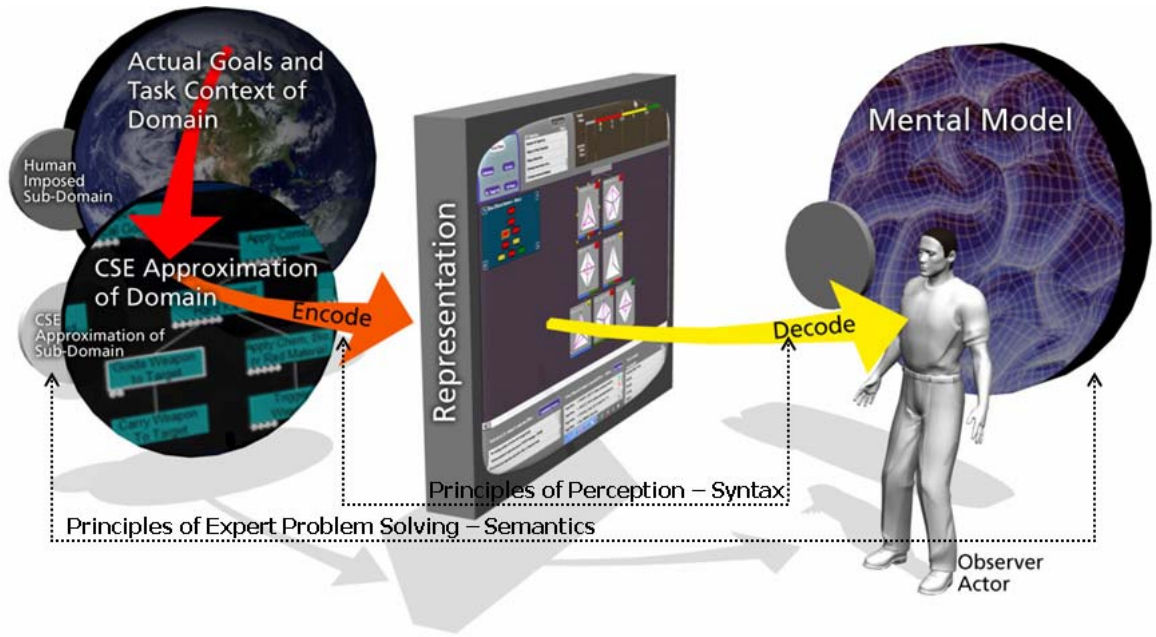

Figure 1. The Mapping Principle (adapted from Woods, 1991) dictates that design of a decision support system must be based on the informational requirements of the work domain, how they are reflected in the representation, and ultimately how they are observed by the user.

The physical characteristics of a decision support system's (DSS) interaction mechanisms and how these characteristics interact with the perceptual capabilities of an observer are considered syntax (individual presentation concepts, and their perceptual gestalt). However, the interaction mechanism's syntax must be considered in the context of what the interaction mechanisms mean. These are the semantics of the interaction mechanisms relating to their underlying meaning – what the interaction mechanisms portray in the context of the problem solving is encoded in its semantics. In order to design an effective JCS for a C2 Center, it is necessary to select a suite of presentation forms that effectively integrate the semantic and syntax components. This means that perceptions about the representational form of the interaction mechanisms correspond to judgments about the underlying functional relationships within the work domain; for example, a relationship

between two elements of a visualization corresponds to a similar relational property existent in the physics of the work domain.

The Mapping Principle suggests that interaction mechanisms in a JCS should be designed so that there is a one to one mapping between the invisible abstract properties of the underlying functional process and the cues or signs provided by the interface. Bennett and Flach (1992) extend this line of thinking by proposing that if the interaction mechanisms produce highly salient emergent features and these emergent features directly reflect the critical information relationships and inherent functional constraints in the domain, then more effective performance is likely to follow. Thus the effective application of the Mapping Principle means that the relational structure of the base domain, that which is understood by a cognitive analysis of the work domain, corresponds to critical structures designed into the interaction mechanism of the JCS.

The critical task for designing a C2 decision support environment is applying the Mapping Principle such that the underlying cognitive work requirements and functional relationships are represented in the decision support environment in which the operators interact. This has several critical, team decision effectiveness, implications:

- **Command team organization** – the command team should be organized and physically positioned so that there is observability and directability of the team's resources in response to changes in the situation.
- **Functional collaboration role of group displays** – group displays should be designed to facilitate intra command team awareness and shared situational understanding across the command team.
- **Functional attention direction role of specialized group displays** – group displays should provide directed attention to events that required the attention of the team.
- **Coordination between individual workstations and group displays** – the entire decision support environment should be designed to increase observability of the C2 situation for all of the team members through a complementary set of individual and group displays, together comprising a single system.

The conclusion drawn from this CSE experience is that in order to be effective, C2 decision support environments must be designed to satisfy the JCS support requirements. Current state of the practice still focuses on technology upgrades without explicit support for decision-making. This paper walks through the design effort for a command and control center and describes the unique design features that resulted from the mission of satisfying these requirements and the resulting impacts.

FIVE UNIQUE SUPPORT REQUIREMENTS

In order to satisfy critical JCS support requirements mentioned above, it is necessary to identify and incorporate affordances into C2 Centers. The search for affordances in the design of C2 Centers is about the (a) relationship of artifacts in the environment, (b) the agents interacting with those artifacts to form a Joint Cognitive Systems (JCS), and (c) the demands placed on the JCS, given the goals of the work domain. Affordances arise in

how the interaction mechanisms are used to handle the demands expressed in the work environment (e.g., anomaly response situations). First, the behavior of the artifacts in the C2 Center should enable changes in the monitored process and provide feedback. Second, actor /agents must have the ability to execute a change in the monitored process and in the control of those processes without disrupting other work activities.

The five generic requirements provide a specification for generating affordances for effective work performance in a JCS. In order to satisfy these support requirements, the designer of the C2 Center must provide mechanisms that allow the operator to manage the complexities of the work domain so that the JCS's overall decision effectiveness is improved.

Observability in a JCS is an important first step for supporting the cognitive work associated with a domain. This is especially true of C2 Centers. Observability in these environments means that the decision support systems must provide feedback so that the operators can see the emerging effects of decisions, actions, and policies (Woods, 1984; Rasmussen, 1985). As C2 Centers increase in complexity, observability of the underlying task processes, actions of individual agents, and automation performance can be used to balance the cognitive demands placed on the operator (Christoffersen & Woods, 2002). Designing interaction mechanisms that improve observability requires that external representations be mapped in such a way as to capture the functional relationships inherent in the domain and to make patterns salient to the operator, not simply providing access to a large set of base data or elements. Additionally, for a JCS to provide adequate observability, it must be event based in order to capture changes in the world. However, it is insufficient to portray the current values of the information; for true observability, the interaction mechanisms must be goal oriented so that they provide the operator with the capability to assess what could happen next, and how that will impact goal satisfaction, and not simply what has happened. Finally, true observability requires that the JCS, in the form of the decision support environment, must be context sensitive and tuned to the interests and expectations of its operators.

The key criterion for whether or not a JCS has achieved observability is its ability to provide feedback necessary for insights into the underlying work domain process – the ability for operators to notice events in the world that they were not expecting. If the JCS cannot do this, then the new technology or new designs inserted into the C2 Center is merely making data available while leaving all of the work to find and integrate the important pieces of information to the cognitive capabilities of the decision-maker. In essence, the JCS has not provided any support, but only added additional work for the operator.

While observability is necessary for the operator to understand the components of the JCS, the designer of a C2 decision support environment must consider the other support functions in order to achieve effective performance. After Observability, the next support requirement that must be addressed is ***Directability***. Directability is the ability to direct/re-direct resources, activities, priorities as situations change and escalate within the work domain. Directability is required so that there can be coordination between the agents and technology that comprise the JCS. This prevents system designers from following into the automation trap where they attempt to have either the technology do it all or have the operator do it all – thus splitting and weakening the JCS. An effective JCS

must provide some capacity for modifying and re-directing the actions and targets of all the agents within the JCS as well as all technological capabilities as conditions and priorities change. Progress on developing interaction mechanisms for directability has lagged due to the corrosive impact of the Substitution Myth and the erroneous assumption that the next levels of technological automation will eliminate the need for coordination (Woods, 2005).

The Substitution Myth assumes that there exists a gulf between people and information processing machines and that indication of trouble (incidents, workarounds, accidents) are evidence that people are erratic unreliable component of a JCS. Those technologists that believe in this myth assume that all they need to do is accelerate development of machines and these machines will be able to substitute for people. This assumption, that better technology will enable the removal of the human-from-the-loop while being strong and persistent, is wrong. The gap between the technological promises and the actual effects that follow each wave of new technology introduction shows that operators and technology must be integrated for work to be accomplished (Woods & Dekker, 2000). One of the keys to this integration is the inclusion of interaction mechanisms that support directability.

JCSs especially require directability support for the autonomous system components. The greater the level of autonomy of automated systems, the higher the need for responsible operators to be able to re-direct the automata as the situation changes. The human monitor needs interaction mechanisms because situations will arise outside the machine's knowledge (brittleness) and where the human has information that is not available to the algorithms.

As the substitution myth points out, automation is limited. Given the high tempo of the situation that can occur in a C2 Center, there must be a means for the human agents that make up the JCS to control all the other components. Therefore, a decision support environment must provide interaction mechanisms that not only provide a means to direct/re-direct resources, but also tools that support the operator's anticipation and projection of future states of the system. Finally, the decision support environment needs directability features that allow operators to input policies for adaptation, and interaction mechanisms that permit intent communications to the other system agents and components.

While Observability and Directability are the two main support pillars, the remaining three requirements are needed for a JCS to be truly effective. ***Directed Attention*** provides the operators in a JCS the ability to re-orient focus in a changing world. Directed attention interaction mechanisms provide a means for coordination across agents where one operator or other component of the JCS can perceive and direct the attentional focus of other agents to particular parts, conditions, or events in the C2 Center. Directing attention and perceiving where another operator's attention is directed are basic aspects of social-cognitive agents (Hutchins 1995). Directed Attention allows the focus of an operator to continuously bounce between a global and a local focus, not only allowing the operator to see where they are, but to know where they should be.

The challenge for JCS designers is how to direct the attention of operators to 'interesting' events or changes in the current situation, and how to filter unimportant data and avoid

the debilitating consequences of false alerts. This is one of the most difficult aspects of decision support environment design. The design of alerts and alarms are often poorly conceived and hobble the effective control of attention in many complex dynamic situations (Sarter, 2002), since achieving coordination of attention requires bidirectional re-focusing where one agent can influence where the other agent focuses. Most automation does not have the facility to interact at this intimate level with the human operator. Therefore the C2 Center designer must incorporate features support this activity.

Resilience is the ability to anticipate and adapt to surprise and error. Given that variability is a key feature of many environments in which JCSs operate, there needs to be interaction mechanisms that provide controls for adaptability, so that the operator-automation team can counter unanticipated variability or perturbations. A downside to a fully automated system is that there is no resilience built into the system, preventing a human to address and adjust to the situational surprise at hand. The resilience requirement forces the designer to provide features that enable the operator to recognize and handle situations which challenge or fall outside that area of textbook competence. In order to accomplish this, resilience interaction mechanisms, just like observability mechanisms, need an underlying functional model of the work domain in order to shift processes, strategies, and coordination when needed. The need for this support requirement is inevitable because of environmental volatility and because rule-based systems or routines are inherently underspecified (Woods et al., 1994). Thus, resilience interaction mechanisms in a JCS provide the operator with the ability to anticipate and adapt to the potential for surprise in the face of complexity and change.

The last support requirement, ***Teamwork with Agents***, can be thought of as a recursive application of the previous four support requirements – moving from a single operator to multiple operator / agents within the JCS. These operator / agents may either be human or machine. The search for affordance in design is a kind of functional claim about the relationship of artifact to practitioner to demands given the goals in which they are operating (i.e., the Mapping Principle). The key for achieving high levels of performance in a JCS, especially a C2 Center, is the ability to support coordination and to synchronize activity across agents in pace with changing situations. The interaction mechanisms necessary to support Teamwork with Agents require features that support building common ground or a shared frame of reference. In addition, the JCS must possess a means to provide anticipatory cues to synchronize agent activities. Finally, the JCS must support the coordination of distributed agents and enable them to share a common intent or focus in order to be effective in their joint activity so that they may balance multiple goals (Klein et al., 2005) simultaneously.

The goal of this paper is to offer an approach for decision support environment design based on a CSE approach in order to extend the relationships between the necessary domain specific cognitive work and the representational form for presenting the information to support those cognitive demands for C2 Centers. To accomplish this goal, the key is to develop a mapping between information on the state of the domain and the dynamic syntax of the decision support environment design concepts. The five JCS support requirements discussed above focus development quickly on high profit areas of support for decision makers. The functions also provide criteria for designing distributed

multi-agent systems. The next section will walk through a generic description of a specific decision support environment design concept along with a discussion of the underlying design issues and how we were able to provide for the necessary support requirements.

UNDERLYING FUNCTIONAL BASIS FOR A DECISION SUPPORT ENVIRONMENT DESIGN

Meaning arises depending on how marks in the medium (e.g., decision support environment) represent some process in the work domain for someone in some goal/task context (the practitioner's cognitive work). Correspondence refers to inter-connection of referent, representation, and observer that influences how the observer finds what is significant or meaningful given the task and goal context. Poor representations create indirect correspondence that makes the cognitive work needed to find meaning more deliberative, more memory intensive, and more vulnerable to various forms of breakdown. This is especially true in a C2 setting where collaboration and coordination issues result from the fact that no one decision-making agent can accomplish all of the domain related work. Direct correspondence occurs when the decision support environment provides the decision-making agents insight into the overall process. Thus, building direct correspondence to achieve Observability presupposes a particular definition of what is informative.

It is this paper's position that the definition of what is informative should be derived from the application of a cognitive analysis of the work domain. For this effort, an Applied Cognitive Work Analysis (ACWA; Elm, Potter, Gualtieri, Easter & Roth, 2003) methodology was used.

ACWA begins with the construction of a Functional Abstraction Network (FAN), a multi-level, recursive, means-ends representation of the essential concepts and relationships of the work domain. The purposes of this component of the analysis are to gain a framework for understanding the underlying work domain and to identify intrinsic properties of the domain that shape the required decision-making.

The FAN was constructed by conducting a work domain analysis to understand and document the goals to be achieved, the relationships between goals (e.g., goal-sub-goal relations, mutually constraining or conflicting goals), and the means available for achieving them (e.g., alternative methods available, pre-conditions, side-effects, preferred order) at ever more increasing levels of abstraction (Woods and Hollnagel, 1987). The resulting FAN is independent of the particular agents (human or machine) accomplishing the specific domain objectives and the functions that must be available and satisfied in order to achieve their goals. In turn, these functions may be abstract entities that need to have other, less abstract or less aggregated functions available and satisfied in order that they might be achieved. This creates a decomposition network of objectives or purposes that are linked together from abstract goals to specific means to achieve these goals.

The FAN is an ACWA-derived artifact that serves as the initial scaffolding that will provide the structure for the design of the decision support environment. This approach contrasts with those who would model the "as is" world and will not be able to develop

an innovative solution. From this model of the work domain, it is possible to derive, organize, and preserve the goals, processes, decisions, and information requirements. ACWA's FAN uniquely illustrates the essential characteristics of a goal-means decomposition as originally described by Woods and Hollnagel (1987), while tailoring the details of this functional model to improve its repeatability and consistency, its applicability across a variety of domains, and its efficiency in designing large scale Decision Support Systems. Specifically:

- A single node is composed of a Goal – Process pair as opposed to considering goals and processes as separate entities. Therefore the relationship between a goal and its process model are exactly 1:1;
- Each process can be modeled qualitatively to represent how it works to achieve a goal;
- Supporting functional nodes are associated with a precise component of the functional process; that is, they support the process in a precise, localized way (Rasmussen, 1986) rather than the whole of the process;
- Relationships within the model can be recursive – processes can have requirements that are supported by more 'abstract' processes;
- Moving up through the network defines supported processes and their impact on goal achievement; moving down defines supporting processes and the requirements for goal achievement.

By coupling the five unique requirements for an effective JCS from above (Observability, Directability, Directed Attention, Resilience and Teamwork with Agents) with a functional representation of the work domain that explicitly represents the decisions within their context of the surrounding cognitive work, a designer can synergistically support the decision making effectiveness of the entire team. A decision support environment designer can design the entire concept; from the layout of the specialized (functionally associated) groups in the floor through the content of synchronized, corresponding displays, each designed for specific decision support purposes.

COMMAND TEAM ORGANIZATION

The layout of the envisioned example decision support environment is based upon a Functional Abstraction Network (FAN) of the work domain. The FAN is a function-based goal-means decomposition of the world confronting decision-makers. It links the purpose(s) of individual controllable entities (e.g., sensors and weapons) with the overall objectives of the work domain (e.g., successfully managing objectives). The FAN provides a framework for making explicit the goals to be achieved in the world and linking the alternative means that are available for achieving those goals.

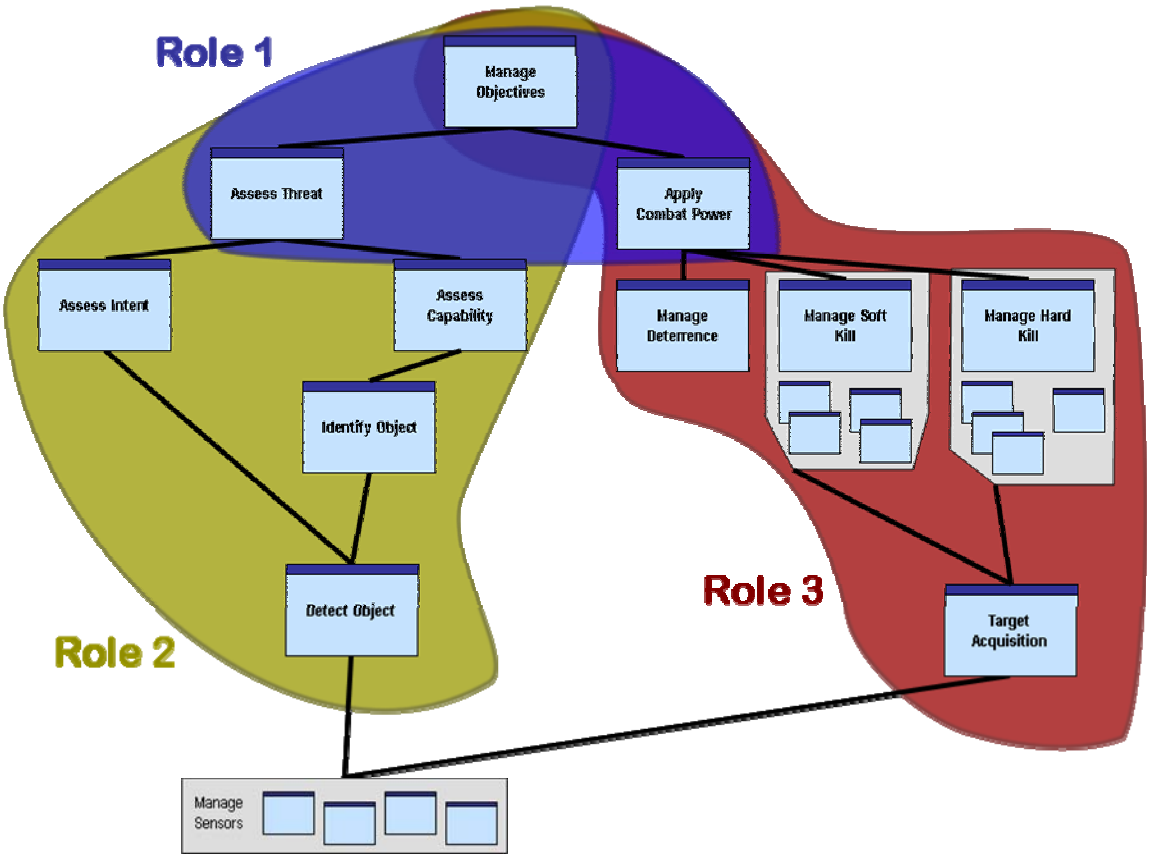

Figure 2. C2 FAN with Notional Role Responsibility Regions

Figure 2 is a simplified representation of a generic Command and Control (C2) FAN that has been used as the kernel for several C2 projects. The attributes of the generic C2 FAN can be utilized to govern the overall organization and layout of the decision support environment. This approach is consistent with Vicente's (1999) assignment of role responsibilities to the abstraction decomposition space. The design of a decision-centered crew is a critical and integral part of the development of the decision support environment and the establishment of a joint (human-computer) team.

For example, the general shape of the structure of the nodes in the FAN is that of an inverted "V." Thus, the left-hand leg of the FAN is associated with assessing the nature of objects in the battlespace, to determine if they have the capability and intent to do harm. The right-hand leg of the FAN deals with determining an appropriate type of combat power to apply to those threats. This two-branch organization, with few cross-connecting links, suggests an allocation of responsibilities within the C2 team. These two regions constitute natural, contiguous regions of responsibility for allocating to decision-makers (e.g., roles 2 & 3).

A third process that is a fundamental part of the FAN is the effective integration of the results of these two other processes in order to manage objectives. Because this is the top-most goal to be achieved in the FAN, it is recommended that a third role position be assigned to this integration process, and to ensure that timely execution of each process is performed. These three roles types form the core of the C2 team. While the above

discussion treats each role type as a singular individual, in practice, there may be multiple operators associated with each of these roles, depending on the workload associated with the roles.

These C2 team members establish part of the criteria for the arrangement of workstations that must be available in the decision support environment. Since the roles and responsibilities of the C2 team members are derived from the FAN, it is logical that the seating arrangement of these individuals within the decision support environment follow the triangular structure of the FAN. Therefore, the work stations are arranged as follows:

- The leader of the C2 team is responsible for the decision-making related to the functional goals that sits at the vertex of the FAN. The operator's work station is located at the vertex of the decision support environment command cluster triangle.
- The Threat Evaluation process constitutes the left-hand leg of the generic C2 FAN. In an analogous manner, these operator's work stations are located in front of and to the left of the team lead.
- The Weapons Assignment process constitutes the right-hand leg of the C2 FAN. In like manner, these work stations are located in front of and to the right of the team lead.

This arrangement provides the team leader(s) with the ability to look over the shoulder of the individuals performing the work domain processes in order to acquire a sense of where their individual attention is focused so as to better understand the problems that each is addressing and something about the problem solving approach that each is taking. Thus, the JCS support requirements of observability and directability are addressed by the physical layout of the decision support environment. The arrangement of the work stations is shown in Figure 3 below.

LARGE SCALE GROUP DISPLAY UTILIZATION

Because C2 teams require communication and coordination among its members, the decision support environment cannot simply be a series of workstations on individual warfighter desktops. Rather, the support environment needs a set of display devices that present results of the various decision-making processes in the context of the C2 team's goals and their current level of achievement. In addition, the LSDCE must address the generic CSE support functions. Members of LSDCE should have a 'workspace' that is made up of:

- **Large Group Functional Displays** (LGFD) mounted on the walls the front of the C2 team. In this decision support environment, two group functional displays are proposed to correspond to the two primary functions.
- **Alarm / Alert Group View Displays** (AAGD) mounted to the side of the group functional displays. Each of these is associated with one of the primary functions.
- **Individual Functional Displays** (IFD) for each warfighter; tailored to the specifics of their function within the overall mission.

This C2 decision support environment concept provides the ability to anticipate and adapt to surprise and errors – the hallmark of resilience. It enables individual team members to explore outside current boundaries, set, focus, or priority, to make cognitive work observable, and to balance the pressure to narrow/over simplify the decision space with comprehensiveness and broadening checks.

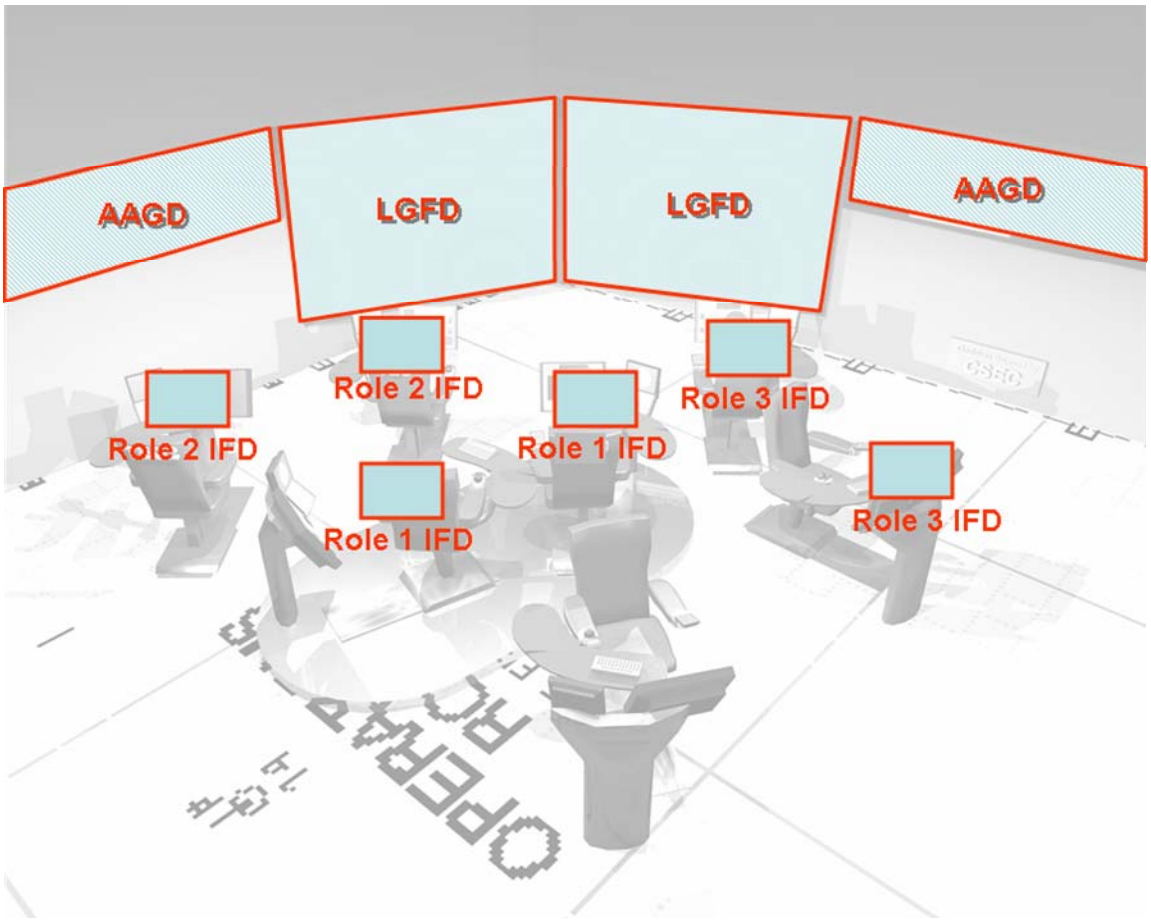

Figure 3. Decision-Centered Operations Room for a Command & Control Team

The LGFDs, AAGDs, and command team organization are the principle means for providing group coordination through Observability, Directed Attention, and Teamwork with Agents. For example, the LGFDs help increase Observability by providing common ground (i.e., a shared frame of reference) and making agents' intent and activities observable to all C2 team members. The LGFDs provide feedback so that the operators can see the emerging effects of decisions, actions, and policies. These representations are mapped in such a way as to capture the functional relationships inherent in the C2 domain and to make patterns salient to all the operators on the floor. Because the LGFDs are organized around the FAN, they have the ability to provide feedback into the underlying work domain process.

The AAGDs support Directed Attention by re-directing agent resources as situations change. They also support coordination functions by seeding other team member activities (i.e., structure & kick start initial activity) and reminding each role member of

alternative possibilities as activity progresses. But the AAGD do not treat alarms like other systems which view alarms as messages from one agent, a first stage monitor, to another, a second stage supervisory agent who monitors multiple channels and whose cognitive resources can be under workload constraints. The alarm is an interrupt signal intended to redirect the attention of the operator from their process monitoring tasks to examine some particular area or topic or condition in the C2 process. Thus, the alarm system participates in processes of joint reference as the signal refers to events in the monitored process in order to direct another's attention to this event.

Because of their role in supporting teamwork and coordinating and synchronizing activities across agents, the LGFDs and AAGDs are 'system paced' displays. The LGFDs present functional depictions of the current state of the components of each of the functional processes at a pace that is consistent with the world events from which those data are derived. While the AAGD directs the attention of the decision-makers to non-normative domain events, the C2 team members cannot directly influence what is displayed on the LGFDs and AAGDs.

However, the individual team members can 'tag' or highlight items on these displays as a means of communicating items of special attention. In addition, the AAGDs are devoted to the display of abnormality indications that are related to the functional processes represented in the FAN. The AAGDs present text messages related to problems within these processes. These could include, but are not limited to:

- Messages about the underlying functional process, or
- Messages about functional goal success.

In addition to the group collaboration design concepts, the operators within the C2 decision support environment require a set of function-based visualizations that provide the operators with a revolutionary work environment that enables them to be agile in response to events in the world that would disrupt their goal seeking performance. As one example, the functional displays should provide the results of inference algorithms in a manner that permits the operator to monitor the overall state of the work domain process with the specifics for any particular element of interest. In order to preserve flexibility and adaptability in role allocation, each IFD is available at every VDU. The individual workstations and their IFDs within the decision support environment should be arranged so that they provide adequate viewing of the LGFDs and AAGDs by workstation occupants. The IFDs also should be arranged to provide effective interpersonal communications between the various members of the C2 team.

ACWA provides a set of requirements that are sufficiently aggregated / abstracted so as to cover the full decision-making scope for a node within the FAN. This follows the CSE support function of Directability, which states that the means for taking control actions in the work domain should be presented at the same level of abstraction as that used for the presentation of data that are used in the decision-making related to those actions. This prevents added (and unnecessary) work and time delays related to locating appropriate control action devices once a decision to take action has been made. *Thus, the total of any agent's decision support environment is the sum of the crew arrangement, LGFDs, AAGDs, and IFDs as an integrated and synchronized decision support environment.*

SUMMARY

The complexity of a C2 work domain requires numerous goals and cognitive work to be managed by a JCS of both decision makers and agents. The current state of the practice to support this multi-human, multi-agent team is for developers to co-locate the C2 operators and they incorrectly assume that coordination, collaboration and better team decision making will naturally occur, through technology updates.

The conceptual design for a Large Scale Decision-Centered Environment is intended to support both individual and team decision-making by designing various Visual Display Units through a purposeful design process – with explicit decision support in mind. This design process utilizes unique, CSE discovered, design requirements (Observability, Directability, Directed Attention, Resilience and Teamwork with Agents) with an explicit functional representation of the cognitive work requirements and functional relationships within the context of its domain (ACWA artifacts).

This complimentary coupling process led to the design of everything from the positions of individual chairs on the floor (Command team organization), how to keep the groups on the same page (Functional collaboration role of group displays), how to direct the focus of operators on their responsibilities (Functional attention direction role of specialized group displays) and how to the manipulate on an individual display to be visualized for the whole (coordination between individual workstations and group displays).

The application of the CSE Principles led to a conceptual LSDCE design that includes large scale group displays for the purpose of establishing and monitoring the team's progress and level of achievement of functional domain goals.

For a Large Scale Decision-Centered Environment to be effective in a C2 work domain, the decision support environment must be designed to satisfy explicit decision support requirements founded within a functional understanding of the cognitive work of the domain. Working to meet these support requirements can be seen as a means to manage the complexities of C2 Center designs, so that its overall decision effectiveness is improved.

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