"How Much is a Pound of C4ISR Worth?"

An Assessment Methodology to Evolve
Network Centric Measures and Metrics for Application to FORCEnet

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ABSTRACT

This paper offers a foundation for an assessment framework involving C4ISR processes in FORCEnet. It collects and expands upon work done by a number of organizations engaged in efforts to structure a process that links traditional and evolved C4ISR attributes, measures, and metrics to network centric outcomes including work being done in support of the Office of Force Transformation and the office of the Assistant Secretary of Defense for Networks, and Information Integration (ASD (NI2)). Using a capabilities based approach to analysis, metrics are recommended and developed to measure organizational performance. Performance improvements such as increased responsiveness and efficiency are measured in the context of Situation Awareness (SA), in a form consistent with the framework of a Capability Maturity Model. This paper offers five levels of Shared Situational Awareness that can provide the basis for assessing an organization in a specific domain relevant to FORCEnet. These resources are intended to guide an organization in implementing a series of increasingly sophisticated practices and activities that can have a significant impact on individual, team, unit, and organizational performance

Introduction

Network Centric Warfare (NCW) is real, and it is daunting—not because it is new, but because of the *apparent* complexity it introduces both in conduct of operations and the means to measure the value of contributing elements. It removes many of the physical and geographic boundaries that have historically driven military operations and decision making. It draws upon resources including people, platforms, systems, and organizational processes in ways that provide unprecedented flexibility and agility to warfighters. It combines these resources to provide tailored "packages" of capabilities to meet transient operational requirements in complex, dynamic environments. It links human, technological, and organizational "systems" in an intertwined and co-evolutionary process that crosses physical, information, cognitive, and social domains.[1] Moreover, it does so in ways that often are responsive to novel and/or unanticipated circumstances. And, it is hard for many to describe NCW succinctly as a concept that can be "*operationalized*."

While jargon, this term reflects the fundamental endgame—the ability to take this new concept and implement it as:

- A set of business processes,
- Warrior development methodologies (e.g., recruitment, training and education, professional development, retention),
- A changed philosophical or doctrinal view of operations,
- Expansion of access to tailored resources by individuals at all operational echelons, and

[1] See Alberts, David S., *Information Age Transformation: Getting to a 21st Century Military*, Washington, DC: CCRP. 2002

- Systems, technologies, and organizational infrastructure that support best the cognitive and decision requirements of a globally distributed human system.

This is a major challenge facing the US Navy as it seeks to implement FORCEnet, the instantiation of NCW in a naval (US Navy and US Marine Corps) context. FORCEnet is central to achieving the transformational operational processes articulated in Sea Power 21 comprising Sea Strike (projection of offensive military capabilities), Sea Shield (projection of defensive capabilities), and Sea Basing (forward presence of military capabilities and resources independent of national boundaries). Sea Power 21 enables these processes through Sea Trial (concept development, experimentation, and validation), Sea Enterprise (business processes that empower and equip the warfighters with needed capabilities), and Sea Warrior (development of a force with the knowledge, skills, and abilities to function effectively across the range of military operations).

FORCEnet binds all of the Sea Power 21 elements in a melded human-technology system of systems. It is this system of systems view that presents a number of challenges in assessing operational value. Traditional concepts regarding attrition-based measures must be thought through to identify means to assess operational outcome in a way that yields a valid comparison between platform-centric and network centric capabilities. And here, the conceptual difference is the location of the seam: at the "lifelines" in platform-centric operations, across function in NCW and FORCEnet. Interoperability becomes a legacy concept and integration the core design principle, a principle requiring *measurement of value, alignment, and tradeoff decisions* regarding a host of capabilities.

Military command, control, communication, computers, intelligence, surveillance, and reconnaissance (C4ISR) architectures particularly must respond to a number of "reconstructed" operational challenges. Many have historical underpinnings. Others require a comprehensive rethinking of operational and organizational dynamics to achieve Sea Power 21. Specifically challenging are:

- Asymmetrical force structures
- Transforming attrition based "targeting" into effects based concepts,
- Asynchronous interactions worldwide in a netted environment,
- Response to globally distributed threats requiring coordinated and mutually aware globally distributed resources,
- New ways of using "old" platforms and capabilities and means to compare effect,
- Leveraging interagency resources and information exchange, and
- The criticality of properly empowered decision making at all organizational levels.

This paper provides an approach to address these challenges. It consists of an introduction, description of the challenge, a notional basis for an analytical framework, means for performance based measurement using a maturity model assessment approach, and suggested applications throughout. The approach includes use of taxonomic and ontological constructs in order to improve FORCEnet C4ISR systems acquisition, decision support, course of action analysis, and other tool development.

The Challenge

Central to defining a toolset and to ensuring the availability of appropriate capabilities packages in the operational space, is the need for heuristics based upon *valid, reliable, and credible measures and metrics* that help answer the essential question of "*what is a pound of C4ISR worth?"*

Answering this question is a significant challenge as the value of C4ISR systems is in the "eye" of the individual assessing them. The challenge is compounded by novel conditions in network centric operations (NCO) and effects based operations (EBO) that:

- Blur traditional operational and organizational lines of communication and authority;
- Emphasize rapidity of information processing, decision making, and operational tempo; and
- Depend fundamentally upon the ability to develop and manage knowledge to achieve discrete outcomes.

For purposes of this paper measures provide the vehicles by which things might be assessed and metrics the mathematical dimensions, capacity, and amount of some thing, process, or effect. A measure in this case might be latency from information availability to decision made in a "decision cycle." A related set of metrics might include time in specific units, number of nodes through which information may have to pass, and effectiveness of engagement (was the threat neutralized?). Others may include decision velocity/volatility, information velocity/volatility, and knowledge velocity/volatility. Here, velocity in terms of both how quickly information was passed to a specific node of interest and volatility in terms of how many times the information changed its content and relevance are addressed. It may be used as a point of comparison between how today's battlegroup and marine force achieves a desired mission (e.g., air defense) and how a future "capabilities bundle" uses resources to achieve a desired effect (no air threat). These examples provide an indication of a bridge between traditional and future approaches.

A number of general C2 design considerations also emerge. These include preparation and training; scope of the battlespace; shared awareness; integration; decision support; decision-making; self-synchronization; dispersal; agility; simultaneity of processes; and continuous and simultaneous operations. Together, these result in a need for new metrics and new ways to apply existing metrics to determine effectiveness and performance in dynamic complex environments.[2]

While it is impossible, and unnecessary, completely to decompose the operational space into its basic structure, it is necessary to provide a framework responsive to challenges

[2] From C2 Literature review, page?? outlined in the Joint Staff J3/Joint C4ISR Decision Support Center's Joint Task Force Command and Control Operational Concept Study Phase I Final Report

affecting the degree of achievement of the needed capabilities. We suggest several initial analytical dimensions that may be developed as an ontological basis to guide this assessment.

First is analysis based on perspective (individual, organizational, and systems). Second is analysis based on knowledge management processes (cognitive, collaborative, and integrative). Third is analysis based on operational scope (tactical, operational, and strategic). Fourth, is analysis based on network centric "domains" (cognitive, information, and physical). Synthesis across these structures results in aggregated assessment of capabilities to sense, understand, influence, act, visualize, and effect that are central to C4ISR value assessment in future, as well as current, military operations. They also provide a self-checking function to ensure relevance of the metrics to a specific situation.

To expand on this notion, enduring elements critical to enabling naval operations provide a point of departure for developing a C4ISR taxonomy. These are:

- *Ability to sense* through globally distributed technological and cognitive systems;
- *Ability to understand* through individual perception, shared awareness, and aggregation of these elements in organizations to result in knowledge mobilization;
- *Ability to influence* friend, foe, and others by conditioning of the operational space through behaviors, lines of authority, positioning, and posture;
- *Ability to act* rapidly, decisively, and appropriately as coordinated across tactical, operational, and strategic echelons;
- *Ability to visualize* the operational space in ways that are relevant to individual users; and
- *Ability to effect* desired outcomes.

Each offers taxonomic offshoots to collect existing metrics, suggest new ones, and guide the user to determine appropriate measures to be used in a given situation. At the end of the day, however, *the practical requirement is for straightforward, flexible, and relevant tools* that help operators determine what, where, when, and how to access C4ISR resources as they are needed. These tools must be sufficiently intuitive that they allow for ready translation in the minds of operators to tangible application in the environments they face. They must retain familiar elements that allow individuals to leverage their base in experience, while fostering their ability to innovate in the face of new challenges. These operator-focused tools in turn must drive development of related tools that properly inform service and DOD level program and acquisition decisions. Here, scarce procurement resources necessitate trades based on perceived value in process, technology, organization, and individual human/warrior domains—value that must be measured.

Given this, the abilities to understand, influence, and act are the primary focus of discussion. They particularly provide an overarching view of the network centric space driving all C4ISR processes as well as assessment of their value. As increasing specificity

is required, layers in a taxonomy can be derived from these elements that are relevant to analytical requirements that help determine value in, and across, contexts. Within this space, attributes can be determined and grouped based on a set of mapping considerations.

The first element, *understanding*, is a knowledge management challenge based upon critical processes including access to relevant information, transforming that information into a personal context applicable to the broader situation, and determining links to operational objectives, or effects, that must be accomplished in a specific time and space—ultimately relying upon SA and the ability to share it.

Compounding the challenge is the need for military C4ISR systems to provide information flow to support understanding at several interdependent, but very different levels: individual, organizational/group, and systems (comprising technological and human elements). Mapping these perspectives to specific processes such as cognition and learning, collaboration, and integration is an important step towards establishing a needed ontology. In terms of generating *understanding*, C4ISR systems provide value in establishing relationships between perspectives and processes that are useful as a foundation for metrics grouping. These relationships can be articulated as (a) Individual-Cognitive, (b) Group-Collaborative, and (c) Systems-Integrative.

Attributes associated with understanding in this construct then can be defined, and metrics determined that provide relevance across changing contexts. It should be emphasized that the last provides for the function of artificially intelligent systems as well.

The second element, *influence*, is a prioritization/utility-based analysis determined by location in the "network." It requires consideration of node, or unit based, interests (how important is accomplishing x to my or others' survival, mission accomplishment, achieving an effect?). It also requires broader consideration of joint/coalition force requirements in a specific operational circumstance using metrics that foster a Blue-Red-Green comparative framework. This ability should provide translation to assessment criteria, course of action analysis, and decision support tools and model development. It should result in identification of both physically proximate and virtual resources as well as the means for applying them to exert desired influence and minimize the ability of others to exert negative influence on oneself. Finally, this element should be derived from an effects based calculus that considers political, economic, cultural, social, infrastructural as well as military dimensions including second and third order propagation of effects. It should not lose sight of the fact that in many cases attrition based concepts still constitute effects. Consideration of system performance in terms of assessed reliability, reachback, processing capability, bandwidth requirements, and many other areas are still relevant.

The third, *action*, is a resources/capabilities assessment tied to a window of opportunity. What do I need to do what I want to do and where is it? Metrics of access, readiness, and distribution are relevant here as well as means to "mass" resources/capabilities to achieve

desired effects including application of “heat, blast, and fragmentation” using kinetic weapons. This ability should also reflect options generated for "how" to act. When is a kinetic option in a purely military context correct? What alternatives may be preferable to traditional tactics, techniques, and procedures? The latter raises questions associated with self-synchronization as well as formal and informal organizational function in a distributed collaborative environment.

Together these elements provide both a taxonomic and ontological core for a model or toolbox of evolved C4ISR metrics. Moreover, a number of “tools”—measures and metrics—are already available to be collected. Numerous service, joint, DOD, and industry organizations have worked together, but more often independently, to develop attributes, measures, and metrics relevant to C4ISR. These reflect a range of perspectives that comprise techno-centric, human-centric, and systems integration foci.

An issue must be addressed, however. Often similar metrics are applied in radically different ways resulting in diverse or conflicting analytical conclusions. Many are predicated on traditional concepts and structures although some have been developed to support emerging NCO and EBO theory. This must be resolved in a post-9/11 environment with time-compressed windows of opportunity (and vulnerability). That moment in time became a catalyst to *realizing* that fundamentally different drivers characterize the current operational environment and that NCW is more than a theory. What is needed now is an assessment methodology that provides a consistent and common vehicle with which to determine the value of C4ISR capabilities in a changed and continuously changing world.

Framework for Assessment

Thus far, use of the term “capability” has been without precise definition. However, before any capability measurement in FORCEnet can be addressed, it is essential to derive a common definition and concept of a capability at least as it relates to FORCEnet.

For our purposes, we define a *capability as that combination of human, technological, organizational, process, and cognitive elements that provides the means to achieve a clearly articulated outcome in a defined context*. This has significant implications in that it requires the ability to link, delink, and relink these elements in ways that are tailored to unique circumstances, often in what are called “mission capabilities packages (MCPs).” It further embeds the human individually and as part of an organization in a complex system of systems. It also requires that intangible cognitive processes be accepted and *leveraged* as part of the system. These latter include elements of emotion, “gut feel,” and other humanistic dimensions that fall more under the “art” than the “science” of military operations. It also should be noted that a capabilities based approach is a fundamental transformation in defense planning. The emphasis is no longer on the “who” (i.e. traditional threat based approach) but rather on the “how”. [3]

[3]Testimony of Art Cebrowski, Director, Office of Force Transformation, before the Senate Armed Services Committee’s Emerging Threats and

In the case of FORCEnet, a hierarchical capability taxonomy has been developed and refined over the past year to articulate aspects of what comprises "FORCEnet." This hierarchy consists of six capabilities at the top level as indicated in Table 1. To facilitate analyses related to these capabilities, elements of the Chief of Naval Operations staff responsible for implementing FORCEnet have developed an initial analytical framework that also is consistent with Assistant Secretary of Defense for Networks, and Information Integration (ASD (NI2)) NCW concepts and analytical resources. This framework further couples newer concepts with existing metrics and systems performance assessment criteria associated with the Universal Joint Task List (UJTL) and service based Mission Essential Task Lists (METLs). A number of traditional measures and metrics also may be applied to analysis of the FORCEnet core capabilities. Table 1 includes descriptions of the six FORCEnet core capabilities and identifies "assessment criteria" that reflect the mapping of C4ISR operational attributes to notional metrics. These metrics have been drawn from an initial review of several C4ISR research efforts which include a recent C2 Concepts and Experimentation Literature Review sponsored by the Joint C4ISR Decision Support Center, the Joint C4ISR Battle Center's Assessment Methodology, the ASD/C3I Architecture Working Group, the National Security Agency/Defense Information Systems Agency sponsored Information Assurance Technical Framework, and Defense Planning Guidance. In general, the metrics are evolving, and it should be recognized that in some cases an attribute could be further operationalized in order to develop a meaningful metric. Many of the metrics and measures mentioned earlier in the paper provide additional candidates for inclusion in the evolving framework as well.

1. Provide expeditionary, multi-tiered sensor and weapon information: The expeditionary, multi-tiered sensor and weapons grid capability uses a full spectrum of manned and unmanned vehicles, platforms, sensors and weapons to provide the Force Commander with what is needed to locate targets and attack them across the depth and breadth of a theater-sized battlespace. Sensors must determine their position, time and movement at the precise time they are reporting their target or other intelligence information. The time and position information of the track provided by sensors in the grid must be properly attributed (e.g., linked to a standard reference frame with uncertainty (error) and confidence level) for it to be accurately understood, represented and fused with other data / information. Many modern weapons are also dependent on precise time and position (including uncertainty) for effective operation.

Attribute	Notional Metric
Accuracy	Correspondence with ground truth-correlation coefficient (0= no correspondence with ground truth, 1= full correspondence with ground truth). Data matrix comprised of relevant information items estimates (for instance: detection, ID, velocity, location, heading, etc.)

Capabilities Subcommittee, 14 March 2003
http://www.oft.osd.mil/library/library_files/trends/trends_30_Transformation%20Trends--17%20March%20Issue.pdf

Consistency	Degree of lack of ambiguity with previous information
Completeness	Percentage of ground truth relevant and necessary for ongoing task
Precision	Error and confidence level for time and position information compared to a standard reference
Timeliness	Degree to which currency matches what is needed (0=no match, 1=high degree of matching between currency level needed and available)

2. Conduct distributed, collaborative Command & Control: To collaboratively manage land, air, sea, and space operational forces in time, space, and purpose to produce maximum relative combat power and minimize risk to own forces. This activity ensures all elements of the operational force, including supported agencies' and nations' forces, are efficiently and safely employed to maximize their combined effects beyond the sum of their individual capabilities.

Attribute	Notional Metric
Shared Situational Awareness	Degree to which the different individual mental models of the situation are integrated into a common operational picture.
Quantity of Posted Information	Percent of collected information posted
Quantity of Retrievable Information	Percentage of nodes that can retrieve various sets of information.
Understandability	Degree to which information is easy to use (0=low degree of ease of use, 1=high degree of ease of use)
Precision	Error and confidence level for time and position information compared to a standard reference
Timeliness	Degree (speed of effect) to which currency matches what is needed (0=no match, 1=high degree of matching between currency level needed and available)

3. Provide dynamic, multi-path and survivable networks: To provide data and information flow seamlessly and transparently to the warfighter across a fault tolerant, adaptable, self-organizing, holistically engineered continuously available network. The data and information flows across a wide range of transmission paths in an interoperable manner with naval, joint, coalition and civil / law enforcement agencies. Platforms and vehicles are able to communicate freely and autonomously with other elements of the architecture thus the existence and functions of the underlying network are transparent to the warfighter.

Attribute	Notional Metric
Capacity	Throughput (1) effective systems capacity = maximum data rate - system overhead rate (2) bandwidth utilization = available data rate / effective systems capacity
Reach	Percentage of nodes that can communicate in desired access modes,

	information formats, and applications
Connectivity	Percentage of time that all required nodes are connected to the network
Information Assurance	Extent to which node supports the assurance of information in the areas of privacy, availability, integrity, authenticity, and non-repudiation
Quality of Service	Measures of jitter, packet loss and latency
Timeliness	Degree (speed of effect) to which currency matches what is needed (0=no match, 1=high degree of matching between currency level needed and available)
Agility	Extent to which the network can maintain QOS in response to environmental changes (incorporates robustness, responsiveness, flexibility, innovativeness and adaptation)
Robustness	Number of differing conditions/environments over which network is capable of operating at a given level of effectiveness (baseline level determined by SME, simulation, analysis, empirical analysis, etc.) Effectiveness of network across varying levels of attack/degradation (baseline level determined by SME, simulation, analysis, empirical analysis, etc.) Number of tasks/missions, which the network is capable of operating at a given level of effectiveness (baseline level determined by SME, simulation, analysis, empirical analysis, etc.)
Responsiveness	The timeliness of the response to an environmental change (baseline level determined by SME, simulation, analysis, empirical analysis, etc.)
Flexibility	Number of options for responding to an environmental change Compatibility of different responses (0=not compatible, 1=fully compatible; determined by SME, simulation, analysis, empirical analysis, etc.)
Innovativeness	Number of novel responses developed and implemented (baseline determined by SME, simulation, analysis, empirical analysis, etc.)
Adaptiveness	Number and timeliness of changes to network structure and processes (baseline determined by SME, simulation, analysis, empirical analysis, etc.)

4. Provide adaptive / automated decision aids: To support warfighter decision making by providing recommended courses of action that are adaptive and based upon knowledge of the operational context, commander's intent, rules of engagement, order of battle, etc. and evolution of the battlespace landscape	
Attribute	**Notional Metric**
Robustness	Degree to which decision aids support decision making across a range

	of situations and degradation conditions
Responsiveness	Degree to which decision aids support decision making which is relevant and timely
Innovativeness	Degree to which decision aids support decision making that reflects novel ways to perform known tasks
Adaptability	Degree to which decision aids support a decision making process with the flexibility to alter decision making in response to the evolution of the battlespace landscape
Consistency	Extent to which decision aids support decision making are internally consistent with prior understanding and decisions
Currency	Extent to which decision aids support decision making that minimizes latency (e.g. Notification - Time of detection = Cueing Time, Time of detection – receipt of refined positional estimate = Update rate, Time of cueing data – time of weapon firing = weapons release time, Firing report received by group commander – weapons firing time = Firing report time)
Precision	Error and confidence level for time and position information compared to a standard reference
Fitness for Use	Relative quality in reference to criteria that are determined by the situation
Appropriateness	Extent to which decision aids support decisions that are consistent with existing understanding, command intent and values
Completeness	Extent to which decision aids support relevant decisions that encompass the necessary: • Depth: range of actions and contingencies included • Breadth: range of force elements included • Time: range of time horizons included

5. Provide human-centric integration: Enhance the ability of warriors to multi-task through all phases of warfare while taking advantage of improved Human-Computer Interfaces which dynamically assign function to human and information systems that best leverage the relative strengths of each (e.g., human decision making in uncertain/ambiguous circumstances, computer systems in situations relying upon high speed complex calculations).

Attribute	Notional Metric
Competence	Distribution of members' knowledge, skills, abilities and attitudes.
Trust	Extent to which members are willing to rely on one another
Confidence	Extent to which members have expectations of the reliability of the organization
Size	Number of team members involved adequate to support mission

Experience	Degree to which team members have interacted in the past on the same task
Diversity	Degree to which team members are heterogeneous or homogeneous across exogenous variables: experience, age, gender, etc.
Autonomy	Extent to which organization is externally or self directed
Structure	• Numbers of layers of authority • Functional Differentiation Effectiveness
Interdependence	Extent to which members depend on one another for resources
Cooperation	Extent to which member(s) are willing and able to work together
Efficiency	Extent to which members utilize one another's resources so as to minimize costs and maximize benefits
Synchronization	Extent to which organization is conflicted, deconflicted, or synergistic
Engagement	Extent to which all members actively and continuously participate
Risk Propensity	Extent of risk aversion

6. Provide information weapons: To integrate the use of military deception, psychological operations, electronic warfare, and physical destruction, mutually supported by intelligence, in order to deny information, influence, degrade, or destroy adversary information, information-based processes, and information systems. (Metrics are under development.)	
Attribute	**Notional Metric**
Lethality	Extent of capability to precisely deliver desired Non-Kinetic (NK) Information Operations (IO) effects.
Coverage	Extent of capability to accomplish IO effects.
Persistence	Extent of capability to sustain IO effects.
Timeliness	Extent of capability to deliver desired NK IO effects at a desired time.
Survivability	Extent of capability to avoid enemy threats, counter ISR, and employ IO techniques to reduce targeting of adversary kinetic systems allowing increased secure maneuvering by ASMD/Deny ISR/SEAD/Networks.

Table 1 FORCEnet Capability Descriptions, Attributes and Metrics

To define where measures may be applied to evaluate *understanding*, key factors and attributes must be organized. Here the individual-cognitive and group-collaborative relationships dominate. It is largely a *process* analysis addressing critical cognitive processes and performance issues in terms of individuals, aggregated teams, and organization. Collaboration among individuals, formal and informal organizations, and *ad hoc* physical and virtual groups are central to the analysis. The types of interactions (e.g., information sharing, course of action analysis, decision making) that need to be

supported, a range of preferred means of interaction (e.g., "face to face," document exchange, graphical reference), the frequency of desired interaction, the range of actors needed in collaboration (e.g., intra-echelon, inter-echelon, joint, non-military), and the reasons for these interactions (e.g., emotion, de-confliction, affirmation, assessment) must all be addressed. Measures of interest are those that address how people perceive and act on information, and what information they need at both the individual and group levels. Systems performance, interoperability, information flow and other measures also pertain.

To define measures to assess *influence and ability to effect desired outcomes* is largely an operations analysis problem. Here the other two analyses are aggregated to answer the question: Were desired operational effects and goals met? This analysis should provide insights into how well human collaboration functioned using the available technical infrastructure. It should also support an understanding of how well the human-machine interface worked. Criteria for assessment and optimization goals should be generated in order to apply measures of performance *and* effectiveness. These measures may address complexity issues associated with the number of nodes involved and timeliness of information exchange to meet specific operational objectives as well as aggregated objectives. They may also address effectiveness in terms of synchronization of activities in time and space.

To define measures to assess *action* is largely a resource analysis problem that depends on the first two analyses while focusing on the performance of the technical infrastructure. It should address specifically the ability of information technology and communications systems (including sensors, visualization, and collaborative tools) to exchange needed data and the information it conveys. Latencies, bandwidth, connectivity, and numerous other technical measures of performance can be identified. This analysis should also provide insights into how well technical capabilities can be maintained in degraded environments, "workarounds," configuration issues, interoperability, and "fusion" of data feeds. Insights into usability issues associated with workstation operations, applications, and ergonomic issues also might be investigated here. From a C4ISR perspective, the water's edge is achieving the ability to allocate resources including weapons and the ability to respond and adapt infrastructure in the face of changing circumstances.

Together these analyses should provide a blended view of system functionality. But they are insufficient without bounding the analysis through the analytical framework discussed earlier: perspective, knowledge management processes, operational scope, and network centric "domains."

Additional measures that adapt traditional approaches to a new environment also should be considered. An example may be "recognition differential"—the ability of an individual or team to note a change in the environment and its implications. This may be useful in assessing information overload and propagation paths for this condition. Such a recognition differential may reflect latencies in another attribute, , relating the time information is available to the time it is used as well as differences in subjective

interpretation. Information overload may be assessed in terms of individual indicators (e.g., human performance), technological indicators (such as bandwidth and data flow), and "decisiveness" as a result of a decision maker having sufficient information to make a decision.

Propagation paths for key information also will relate to identifying the means for mitigating and taking advantage of complexity. A path approach should also include the number of nodes required for a "decisive" interaction. It also may include "amplification," that is needs driven by non-linear aspects of complex interactions that increase or decrease the speed of decision making—perhaps in the form of errors or rate of gaining shared awareness.

Additional measures may include dispersion, vulnerability, risk, readiness, and number of decision elements. Dispersion may be driven by time-space separation of actors and include such things as how long it takes to reach-back and integrate key subject matter experts in analytical and decision support functions. Vulnerability may be addressed in a range of dimensions to include error propagation, trust in information and sources, effects-based "windows" of decision-making, and more traditional assessments regarding information assurance and the operational impact of lost information inputs. For example, risk relates closely to vulnerability and may be assessed as a function of the interaction of key vulnerability and threat factors at any given point in time. Readiness may be determined by the availability and timely use of organically and non-organically controlled assets in terms of key points in time. Last, the number of decision elements may be assessed to indicate the complexity and sufficiency of information requirements across a range of analytical dimensions.

The metrics applied in the analyses and assessment phase will be dependent upon the assumptions that define them. They should provide emphasis on quantification of performance and effectiveness. These measures and metrics may be key to assessing an objective state of shared awareness. While the measures and metrics described above provide a set of potentially useful "types," specific measures to be applied should be drawn from a consolidated pool of existing and evolving activities in the naval and joint community.

Performance Based Measurement: Situation Awareness (SA)

Individuals, organizations and teams can each be regarded as an independent cognitive system. Where individuals collaborate inter/intra organizationally, often in a ubiquitous and virtual workspace, they aggregate their cognition into shared situation awareness (SSA). Multiple channels permit the storage and mining of information that can be discovered, acquired, shared and leveraged at each level. First, individuals develop their independent SA. The second element of the process is the effective *communication* of individual perceptions to the other members of the group, for the purpose of consensus building. Third is the subjective aggregation of those inputs by team members. Last is objective visualization of a common base of perception, often in visualization tools. In this process, emerging technologies for decision aids like intelligent agents, data mining

and complex modeling offer the potential for large volumes of data to be collected, processed, and displayed without overloading users. Correlated data becomes information that is converted into knowledge which relies upon accurate situation awareness.

The expected result of leveraging virtual interactions without the barriers of time or space should be a more agile and responsive organization. More fundamentally, information should be sufficiently available that the network should naturally foster collaboration. However, the analytic space is not clearly bounded. The challenge in the analysis process is that network centric warfare explicitly involves the human component and the other issues that arise from the complex interactions of distributed teams. These teams create a multi-dimensional analytic space that includes tightly connected interactions between platforms, systems and people. Often these interactions are subjective and therefore measures of effectiveness are impacted by elements such as organizational development and culture, morale, doctrine, training and experience.

SA "quality" then is the degree to which SA accurately comprises an objective assessment of that reality, an assessment that can be shared and then interpreted for application in a given individual's context. The difference between knowledge-based and performance-based techniques for evaluating situation awareness reflects taking measurements at different points in the process of user cognition. Performance-based measurements have been determined to ascertain the timing and substance of a user's reaction to realistic situations, while knowledge based techniques are more appropriate for providing a detailed, theoretical assessment of the subject's situation awareness.[4] Performance-based measurement is complementary to knowledge-based measurement in the human factors analysis. Based on the best current practices in fields such as human resources and organizational development, Capability Maturity Model[SM] (CMM) based approaches often help organizations to characterize the maturity of their work-force practices, guide a program of continuous work-force development, set priorities for immediate actions, integrate work-force development with process improvement, and establish a culture of excellence.[5] This approach facilitates the evolutionary improvement path from ad hoc, inconsistently performed practices, to a mature, disciplined development of the knowledge, skills, and motivation of the work force.

We suggest a variant of the CMM to support SA maturity assessment. This variant consists of five maturity levels that institutionalize a level of capability for nurturing the talent within the organization, developing effective teams, and successfully managing the people assets of the organization. The benefit of CMM to the notion of SA is that the CMM guides an organization in implementing a series of increasingly sophisticated practices and activities for developing and motivating its workforce which can have a significant impact on individual, team, unit, and organizational performance.

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[4] Pritchett, A. R. H., R.J. & Johnson, E.N. (1996). Use of Testable Responses for Performance-Based Measurement of Situation Awareness. Presented at the International Conference on Experimental Analysis and Measurement of Situation Awareness, Daytona Beach, FL

[5] Harigopal, U. S., Antony, (2001). "Cognizant Enterprise Maturity Model (CEMM)." IEEE Transactions on Systems, Man, and Cybernetics: Special Issue on Knowledge Management.

Level	Focus	Process
5 Transformational	Agent based communication; establishing a process for adapting processes to support operational contingencies; establish knowledge delivery mechanism to provide knowledge to strategic partners; process optimization	Evaluation of performance and effectiveness on a continuous basis Identify adjustments and potential improvement to the fusion process Determine source specific data requirements for processing Recommend allocation and direction of resources in support of the mission Understand mission, opportunities and risks, adversary's capabilities and limitations, analysis of possible outcomes, and adversary's intent
4 Predictable	Concepts embedded in data translated into a common ontology; data mining for patterns and relationships; presentation of knowledge based upon the user's learning profile; network of multiple portals enables the real-time aggregation of disparate knowledge	Estimate capabilities, i.e. number and location Predict enemy intent based on actions, communications and enemy doctrine Identify threat opportunities - ID of potential opportunities for enemy threat Assess from multi-perspectives Analyze prediction of offensive/defensive results of hypothesized engagements Understand mission, opportunities and risks, adversary's capabilities and limitations, analysis of possible outcomes

Level	Focus	Process
3 Defined	Data is aggregated in a central data base; data from multiple operational systems can be extracted on demand; richer artifacts of the process are stored and organized; data presentation includes summaries and analysis; collaborative tools capture the timeliness, breadth and depth of subject matter experts	Estimate relationships among aggregated objects including events/activities Interpret within context weather, terrain and other environmental considerations Assessment from a multi-perspective (i.e. Blue, Red & White viewpoints) Understand mission, opportunities and risks, adversary's capabilities and limitations
2 Repeatable	Data repository mechanism provided to capture individual input and retrieve data; forum provided for distributed collaboration	Focus on individual objects Associate sensor outputs w/specific known objects or initiate new objects Use sensor data to refine the best estimates of current positions for each hypothesized object. Understand mission, opportunities and risks
1 Initial	Limited collaboration, data fusion or correlation	Align data with respect to time/space Relate newly received observations to existing track Comprehend basic classification of emitters, platforms, etc. Understand mission

Table 2 Five Levels of Situational Awareness

Level 1: The Initial Level

At the initial level, the organization typically does not provide a stable environment. During a crisis, planned procedures are abandoned. Success depends entirely on having an exceptional leader. Even strong tactics, techniques and procedures (TTP) cannot overcome the instability. Capabilities of Level 1 organizations are typically unpredictable because the process is ad hoc and occasionally chaotic. Few processes are defined. Performance depends on the capabilities of individuals and varies with their innate skills, knowledge, and motivations. Therefore performance can be predicted only in terms of

individual rather than organizational capability. This is the lowest level of data fusion and often that fusion does not exist. Without any data fusion, SA is based on the manual correlation and/or aggregation of data. This would also correspond to the lowest level of individual SA, which is the fundamental perception of important information.

Level 2: The Repeatable Level

Policies and procedures are established and institutionalized. Planning and managing new tasks are based on experience with similar projects, which allow organizations to repeat successful practices developed in earlier tasks. An effective organization's process is practiced, documented, enforced, trained, measured, and able to improve. Problems in meeting goals and performance standards are identified when they arise. Level 2 organizations can be summarized as disciplined because planning and execution of the mission is stable and earlier successes can be repeated. The key process areas at Level 2 focus on instilling basic discipline into workforce activities. From the standpoint of data fusion the focus is on individual objects. SA as a construct is still fundamentally about basic perceptions of important information.

Level 3: The Defined Level

The Level 3 organization exploits effective policies and procedures that are well documented and integrated into a coherent whole. There is a dedicated component organization that has been institutionalized and is responsible for the organization's process activities, i.e. quality control/analysis. An organization-wide training program is implemented to ensure that the staff and managers have the knowledge and skills required to fulfill their assigned roles. A well-defined process can be characterized as including readiness criteria, inputs, standards, and procedures for performing the work, verification mechanisms (such as peer reviews), outputs, and completion criteria. Because the process is well defined, management has good insight into the level of performance that is based on a common, organization-wide understanding of activities, roles, and responsibilities. The key process areas at Level 3 are knowledge and skills analysis, workforce planning, competency development, career development, competency-based practices, and participatory culture. Data fusion is devoted to organizing the hypothesized objects into a big picture of what is happening. The big picture is described in terms of groups or organizations of objects so that decisions can be made by decision makers about how to use friendly organizations. SA goes beyond perception and encompasses the combining, interpreting, storing and retention of information. At this level of SA, operationally relevant *meaning* and *significance* of the Level 2 data is being considered.

Level 4: The Predictable Level

The organization sets quality goals that are measured as part of an organizational measurement program. Processes are instrumented with well-defined and consistent measurements. Organizational control over performance relies upon narrowing the variation in performance to fall within acceptable quantitative boundaries. Meaningful

variations in process performance can be distinguished from random fluctuations. The performance of Level 4 organizations is predictable because performance is measured and operates within measurable limits. These measurements permit an organization to predict trends in process quality and when the quantitative bounds of these limits are exceeded, action is taken to correct the situation. The key process areas at Level 4 focus on mentoring, team building, team-based practices, organizational competency management, and organizational performance alignment. At this level the data fusion is more about the situation and what is known from enemy doctrine and objectives to predict the strength and vulnerabilities for both the threat and friendly forces. Almost at the highest level of SA, there is some capability to forecast future situation and events. Given a high level of understanding of the situation future events and their implications to permit timely decision-making.

Level 5: The Transformational Level

At Level 5 the organization is focused on continuous process improvement. The organization identifies weaknesses and strengths proactively, with the goal of preventing the occurrence of negative performance. Innovations that exploit best practices are identified and transferred throughout the organization. Level 5 organizations analyze defects to determine their causes. Level 5 organizations are continuously striving to improve the range of their process capability, thereby improving their performance. Improvement occurs both by incremental advancements in the existing process and by the introduction of innovations. The key process areas at Level 5 address continuous improvement for personal competency development, coaching, and workforce innovation. The fusion process at this level examines what is unknown in the context of the situation and threat and then develops options for collecting the information.
At the highest level of SA, relying more on tacit communications, organizations are self-synchronized and are heavily dependent on future predictions.

Evidence to date suggests that the predictability, effectiveness and control of processes improve as the organization moves up the five levels of CMM. This offers insight into addressing a major organizational challenges to transformation in the Department of Defense that often dominate the technological challenges. As rapid advances in information technology enable network centric warfare to move from concept to the battlesphere, traditional metrics need to be reevaluated. Performance improvements such as increased responsiveness and efficiency need to be measured in the context of Situation Awareness and are fundamental to guiding process improvements in the storing, organizing and processing of information. CMM is a useful framework for the measurement of SA and provides a performance based assessment of the value of C4ISR.

Summary

In this paper, we have provided a foundation for an assessment framework involving C4ISR processes in FORCEnet. This framework reflects and expands upon work done by a number of organizations engaged in efforts to structure a process that links traditional and evolved C4ISR attributes, measures, and metrics to network centric outcomes

including work being done in support of the Office of Force Transformation and the office of the Assistant Secretary of Defense for Networks, and Information Integration (ASD (NI2)). Using a capabilities based approach to analysis, metrics have been recommended and developed to measure organizational performance. Performance improvements such as increased responsiveness and efficiency have been described in the context of Situation Awareness (SA), and in a form consistent with the framework of a Capability Maturity Model. Finally, we have provided five levels of Shared Situational Awareness that can provide the basis for assessing an organization in a specific domain relevant to FORCEnet. Hopefully, continued work will result in implementing a series of increasingly sophisticated practices and activities which can have a significant impact on individual, team, unit, and organizational performance.