ITEA Journal 2010; 31: 232–239

The Cognitive Performance Component in Networked System of Systems Evaluation

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The Army's Future Force requirements contain ample descriptions of the physical architecture for manned and unmanned systems, and a multilayer network to which the Army will eventually migrate. Requirements specifications that will allow those entities to seamlessly function as an interoperable and integrated entity also exist. However, few descriptions exist of the cognitive performance requirements that will be essential for the individual, team, and units to perform command and control function because they increasingly rely on a networked system of systems. Even more elusive are the methods for evaluating, in an operational environment, whether the cognitive performance requirements have been met. Increased task complexity, uncertainty, workload, distributed command and control, battlefield visualization, and situational understanding are but a few of the areas that a future networked system of systems design is required to address.

The volume of communications and information exchange within and between layers of command call for simplification in tools and processes provided to warfighters. Networked-enabled command and control must allow warfighters to manage these increasing demands at operational tempos that drive proactive versus reactive maneuvers against a highly adaptive threat. This article describes a number of factors that affect the networked system of systems' ability to enhance cognitive performance and support the levels of coordination and collaboration required for distributed command and control in a complex battle space. Considering these factors in the evaluation of a networked system of systems is important given the increased levels of higher order cognitive processing necessary to operate in such an environment.

Key words: Cognitive performance; networked system of systems.

The 2009 Army Posture Statement characterizes the global security environment as "more ambiguous and unpredictable than in the past." Recent conflicts have demonstrated greatly increased complexity in planning and executing the range of military operations required for engaging in irregular, nontraditional, disruptive, and sometimes catastrophic warfare. As amplified in the Capstone Concept for Joint Operations (DoD, 2009), rapidly changing conditions in the joint operations area are posing significant challenges for commanders and are creating taxing demands on their ability to generate courses of action (COAs). These COAs are often in collaboration with other service, multinational, and interagency contributors to combat highly adaptive adversaries utilizing unconventional tactics (Department of the Army, 2007). These challenges can only be met with human and technological capabilities that enable greater levels of collaboration and information sharing, which then lead to self-synchronization. Aberts and Hayes (2003) identified these COAs as critical capabilities for the "next revolution in military affairs," more prominently known as network centric warfare, described by Cebrowski and Garstka (1998).

Unarguably, the greatest capability demand for achieving victory in the range of military operations is the development of technologies, techniques, tactics, and procedures that support the generation of proactive COAs. Such capability demands require effective employment of sensors, systems, and decision aids designed to deliver human and sensor inputs, fuse them into information sources supplied to increase situational awareness, and support making resolute decisions that can increase speed of command. Clearly, these demands cannot be met through the application of human abilities alone. Several types of technologies are required to accomplish this feat. Further, these technologies cannot operate in isolation. Implementing network centric warfare requires assurance that a multitude of networked systems can communicate and exchange information, hence a networked system of systems (SoS); there must be assurance that they provide the qualities and characteristics that complement the way warfighters execute missions, versus providing ones that may ultimately burden them. Kevin P. Byrnes, General, United States Army, Commanding, said the following (Department of the Army, 2005):

> *"Technological advances alone will not constitute transformation. Our most critical asset is not technology, but the critical thinking of our Soldiers and leaders." (Department of the Army, 2005; Kevin P. Byrnes—General, United States Army, Commanding)*

A networked SoS naturally implies using computer technology to manage the transmission of information between two or more systems, or between devices attached to them. Conley (2009) further describes these systems to include weapons and vehicle platforms as nodes within this SoS and that these platforms as network nodes must be equipped with communications capabilities such that a network "sees" them no differently from any other networked system. These capabilities are usually generated from efforts within the discipline of computer networking, which can be considered a subdiscipline of telecommunications, computer science, information technology, or computer engineering. In practice, however, it's the integration of capabilities from these subdisciplines that synergistically provide the capability to move information, in a variety of formats, from one location to another. To some this capability seems quite mysterious; to others it's the simplistic application of modern technology, but there's likely little argument that it becomes a very complex issue to all when you also consider requirements for this capability to provide the exact information an individual needs to make decisions and operate systems anytime he or she needs that information, and from any location around the globe.

From an engineering point of view, developing a networked SoS is only limited by the available technology, but from the users' point of view, the requirements go far beyond technological feats. The most technologically advanced networked SoS could become a hindrance rather than an aid to the user if it doesn't support the way he or she needs to use it. Of course, people can usually modify their behaviors to adapt to technology, but there are potential risks in adopting an attitude that users *should* do that instead of providing technologies designed to better coincide with their behaviors.

Within the context of the Army's concept for unified battle command (UBC), the remainder of this article focuses on the factors that shape the way people use networks and networked SoS, influence how effectively they are able use the embedded capabilities, and determine how much they are willing to rely on them to execute their tasks. In addition, a number of other factors that shape not only individual performance but also collectively shape the performance of teams and organizations planning and executing net-centric operations.

Unified battle command

The UBC concept identifies a strategy that utilizes a SoS approach to federate several battle command applications. This federation delivers a suite of integrated battle command functions applicable to all Army echelons. The training and doctrine command capabilities manager for battle command identified the battle command essential capabilities (BCEC) that are essential for commanders to execute battle command in the realm of full spectrum operations. The integrated suite of applications is designed to provide a "robust" network, seamless sharing, and displays of "relevant" geospatial information, and a "standard" collaboration capability within and across all command levels, to include extension to the individual soldier. These are considered to be the critical components of the BCEC, supported by the UBC concept, and are further described in the following discussion.

Battle Command Essential Capabilities (BCEC)

An integrated capabilities development team for battle command identified 10 essential capabilities to implement the UBC concept. Those capabilities are (Department of the Army, 2008):

1. A robust network capability. The force must possess a commander-centric, secure, integrated, and adaptable communications network consisting of line-of-sight and beyond-line-of-sight means.
2. Execute tactical network operations. Commanders need the ability to have effective tactical network operations (network management) conducted and provide guidance to allow allocation of network resources to maximize performance through all phases of the joint phasing model.

3. Display and share relevant information. The Army's battle command system must enable the receipt and dissemination of essential information for display on the common operational picture from dismounted soldier through army-level command posts. This includes symbols, graphic control measures, friendly and enemy information, civil considerations, and the operational environment from disparate information systems.
4. A standard and sharable geospatial foundation. Commanders and leaders need common geospatial information to enable all battle command essential information requirements, create a common map foundation, and display and share this information on a tailorable and interoperable common operational picture.
5. Enable collaboration. Commanders and leaders need a common suite of collaborative tools to allow establishment of a collaborative environment to achieve shared understanding and ensure unity of effort in both high and low bandwidths.
6. Create and disseminate orders. The Army's battle command system must be able to create, change, and distribute mission orders (both voice and written) to include attached graphics between command post, platforms, and leaders.
7. Battle command on-the-move. The commander must have the ability to maintain situational awareness, make timely and informed decisions, and position himself at the decisive point during the battle.
8. Execute a running estimate. The Army's battle command system must be able to support running estimates by continuously gathering and tracking information to support tactical decision making by providing a continuous assessment of current and future operations, including conclusions and recommendations.
9. Joint, interagency, intergovernmental, and multinational interoperability. The Army's battle command system must be able to exchange relevant operational information with joint, interagency, intergovernmental, multinational partners; nongovernmental organizations; and contractors.
10. Rehearsal and training support. The Army's battle command system users must be capable of preparing for operations using embedded rehearsal and training tools that accurately represent the spectrum of missions and environments.

In addition to the BCEC, UBC calls for implementation of the battle command framework of the Training and Doctrine Command 2007 as shown in *Figure 1.* This framework identifies 10 functional battle command concepts. Each of the BCEC and functional battle command concepts has a technological solution within the networked SoS, but there are a number of factors that need to be addressed to support the cognitive performance of users of the networked SoS.

Significant advances have been made in technologies to acquire and move abundant levels of information across a networked SoS and deliver it to the appropriate user. However, human brains cannot consume and make sense of the sheer volumes of information presented within a timeframe to make it usable for planning and conducting high operational tempo (OPTEMPO) missions. The remainder of this article provides a comprehensive, though not exhaustive, list of factors that affect cognitive performance and how some of those impacts degrade effective use of a networked SoS to execute battle command processes.

Factors affecting cognitive performance in net centric operations

While the BCEC and functional battle command concepts support requirements definition for a networked SoS designed to support the battle command framework, those requirements ultimately serve to optimize collaboration, situational understanding, visualization, and information sharing capabilities. The end state for optimizing these capabilities is optimized command decision making (CDM), both in speed and effectiveness. It is the speed at which commanders receive the information they need to develop the necessary levels of situational understanding; visualize the battlefield; collaborate with other services, nations, or agencies; and make effective decisions to achieve desired end states that support achieving the ultimate end state of thwarting or defeating intentions of the adversary. *Figure 2* provides a graphic illustration of the dependent relationships between these capabilities that support CDM. This premise serves as the foundation for the discussion that follows regarding the factors that contribute to, or detract from the development of these capabilities.

There are a number of factors that contribute to the development of capabilities that affect speed and effectiveness of CDM. These factors are both internal and external to the decision maker. Internal factors relate to those that *form* the inherent abilities of the decision maker, while external factors are those that *affect* the inherent abilities of the decision maker. *Figure 3* outlines a number of the internal and external factors that impact cognitive performance, and hence contribute to developing the primary capabilities that

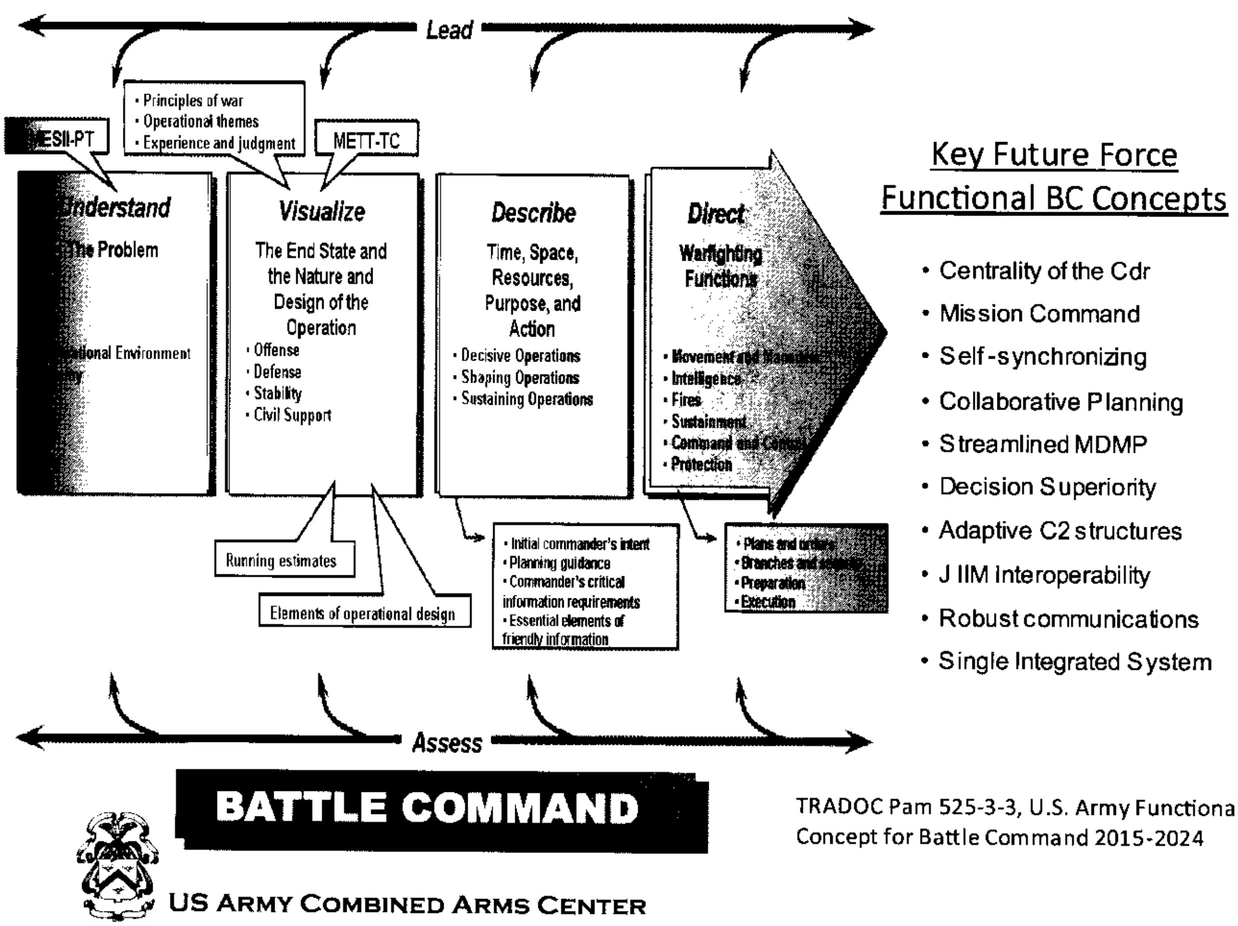

Figure 1. The battle command framework.

support CDM (see *Figure 2*). Internal factors are grouped into the categories of ability, disposition, and state, and external factors are grouped into automation, environment, and team. This is certainly not an exhaustive list, and the intent of this article is not to delve into all aspects of the effect of these factors on cognitive performance but to identify some of those that can be observed and/or measured for their impact on the primary capabilities supporting CDM. The following section is dedicated to identifying these factors, providing a brief description of each, and some of their impacts on cognitive performance, and why it is important to consider them in the test and evaluation of a networked SoS.

Internal factors

Shaping factors that affect cognitive performance and are internal to an individual are those he or she brings to the situation. They are a culmination of the things that are inherent to the individual's genetic makeup, learning experiences he or she has been exposed to, references committed to memory, and physiological condition(s) that determine his or her ability to cope with a set of circumstances in an operational setting. The author has grouped these factors into three areas: (1) ability, (2) disposition, and (3) state.

1. Ability. Shaping factors in this area primarily center on formal education, occupational training, and repeated exposure to events from which an intuitive reaction or thought process is developed and repeated when a like event is presented again. These are similar to learned behaviors such as testing how hot a cup of coffee is before taking a drink because a burned tongue had resulted sometime in the past when the temperature was unknown.

Professional military education provides the foundation for knowledge that warfighters need to plan and conduct military operations. Training provides warfighters the opportunities to use the knowledge gained from professional military education. Skills and abilities are the by-products of education and training. They are what has been gained by the individual as a

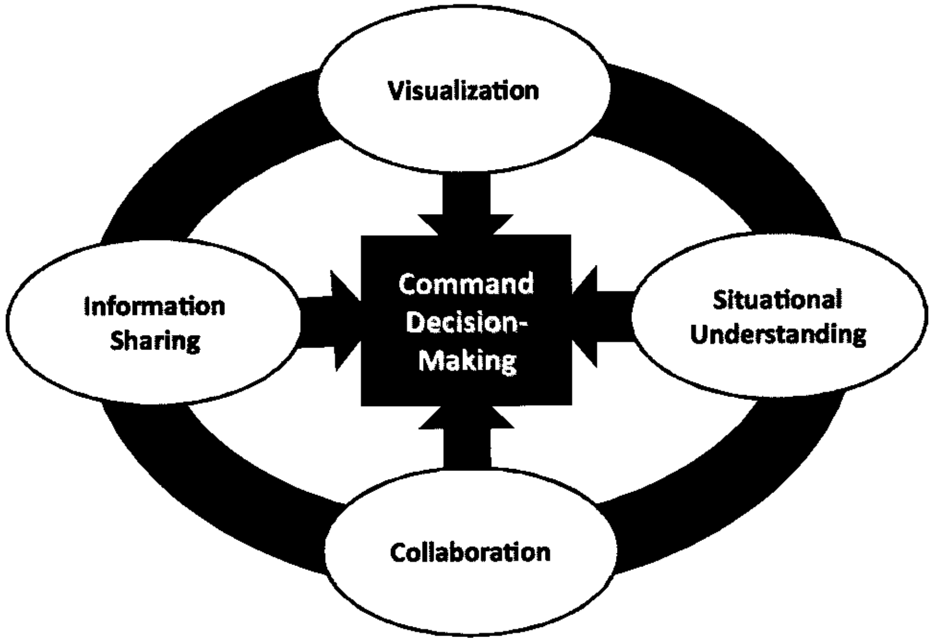

Figure 2. Primary capabilities supporting command decision making.

result of prior education and training. In a situation requiring a decision, education, training and the resulting skills and abilities obtained influence the quality of the decision made. It is the repetition and richness of experiences, however, that provide decision makers the opportunity to store in memory an intuitive response to a situation. Those stored memories contribute to developing a mental model that can be used in a similar situation and thus increase the speed at which the decision is made. Klein et al. (1993) refer to this as recognition-primed decision making, which has since become the accepted theory for how individuals make decisions in complex, time-constrained circumstances, provided the mental model for that situation has been developed.

With respect to the cognitive performance of an individual engaged in planning and executing military operations using a networked SoS, the abilities of the individual must be considered when evaluating the performance of the networked SoS. Because the capabilities of the networked SoS must support a decision maker in developing the most effective and rapid decisions he or she can, the abilities of that person must be considered before evaluating whether the networked SoS has met the prescribed requirements.

Internal Factors
- ❖ **Ability**
  - Education
  - Training
  - Experience
  - Skills/Competencies
  - Mental Models
- ❖ **Disposition**
  - Personality
  - Culture
  - Motivation
  - Need for Cognitive Structure
  - Risk Aversity
  - Uncertainty Tolerance
- ❖ **State**
  - Workload (physical/mental)
  - Fatigue
  - Nutrition
  - Awareness
  - Trust
  - Uncertainty

External Factors
- ❖ **Automation**
  - Networks
  - Decision Aids
  - Collaboration Tools
  - Information Filters/Fusion
  - Presentation (visual/auditory, other)
- ❖ **Environment**
  - Temperature
  - Austerity
  - Motion
  - Threat/Safety
  - Facilities
- ❖ **Team**
  - Shared Awareness
  - Unity
  - Back-up
  - Communication
  - Role Identity

Figure 3. Shaping factors that affect cognitive performance and the development of primary capabilities supporting CDM.

2. Disposition. Everyone comes into the world with inborn traits. In addition, people develop additional traits as a result of experiences throughout their lives. Regardless of their source, these traits influence the ways in which individuals use technology. Traits attributed to personality and culture factors tend to influence how people feel about technology, while factors such as motivation, need for cognitive structure, risk adversity, and uncertainty tolerance tend to influence how and how much people use technology. For instance, the more adventuresome and adaptive an individual, the more likely he or she will explore the potential for technology to support accomplishment of tasks. Conversely, the more risk adverse or lack of tolerance for uncertainty, the less likely he or she will seek help from technology.

Motivation to use technology can stem from a number of sources; however, necessity can often rule over desire depending on the perceived or real usefulness and/or ease of use of the technology. For the most part, the networked SoS supporting planning and execution of military operations leads to necessity for using it, unless it is possible for the user to develop a work-around that he or she finds more satisfying than relying on the technology available to accomplish a task.

An individual's need for cognitive structure refers to how much ambiguity in the information he or she is obtaining can be tolerated before it leads to dissonance, stress, uncertainty, or confusion. According to Roney and Sorrentino (1987), people are either certainty or uncertainty oriented. Certainty-oriented people tend to bin information as valid or invalid, and ignore information that is either inconsistent or ambiguous. Uncertainty-oriented people, on the other hand, have a greater ability to deal with the same ambiguous or inconsistent information by binning it as such and allowing the possibility for its usefulness. Therefore, when validating whether a networked SoS meets the users' requirement through the use of feedback from the user, it is necessary to know how much uncertainty users can tolerate before evaluating whether the prescribed requirements have been met.

Risk adversity and tolerance for uncertainty also determine how much an individual is willing to trust whether technologies provided will actually do what the individual is told they will do. If trust is high, willingness to use (without doubt) the technology will be higher. If trust is low, the individual's willingness to rely on the technology decreases. The factor of trust is further examined in the next section on state.

3. State. Shaping factors in this area are the physiological conditions that affect an individual's normal cognitive performance abilities. Considerable research has been conducted in assessing the effect of state factors on cognitive performance. Assessing cognitive performance in a net-centric environment is more critical to the evaluation of system or SoS performance because there are greater cognitive demands on individuals in a net-centric information-driven environment. Wesensten, Belenky, and Balkin (2005) explain that the ability to integrate information, anticipate, and plan depends on the brain's prefrontal cortex to execute. Various physiological stressors (or performance shaping state factors), such as high workload (physical and mental), fatigue, and poor nutrition degrade the functioning of the prefrontal cortex, and by extension degrades cognitive performance in general.

Lack of trust, too much uncertainty, and poor situational awareness, while not direct stressors to the prefrontal cortex, can also degrade cognitive performance. When trust in the information provided from technological devices becomes low, individuals feel uncertain that they have the necessary information to make a decision, which leads to increases in decision making time. If they learn to distrust the technology, or in this case the networked SoS, they can fall into patterns of ignoring the information produced when they shouldn't. If they become overconfident that the networked SoS is flawless and begin to overtrust the information, never questioning its validity, equally bad decisions can be made with equally bad outcomes.

Situational awareness is in itself a key capability supporting CDM and has received the recognition as being the primary enabler for decisive victory in planning and executing military operations. If the information provided from a networked SoS is not sufficient, poorly represented or formatted, and/or lacks the salient cues to adequately result in an accurate, current, and relevant level of situation awareness, decision makers are at risk for making poor decisions, not because of their inherent abilities, but because the networked SoS has not provided the right capabilities to ensure that the decision maker is equipped to make optimal decisions.

Understanding an individual's state while engaged in the use of a networked SoS is important for evaluating whether it meets the user's requirement for it to support execution of military operations.

External factors

Shaping factors that affect cognitive performance and are external to an individual are those that the situation and surroundings impose on him or her. Just as with internal factors, they are a culmination of things that determine his or her ability to cope with a set of circumstances in an operational setting. The author has grouped these factors into three areas: (1) automation, (2) environment, and (3) team.

1. Automation. Shaping factors in this area primarily center on the capabilities within the networked SoS. They include the networks themselves, and all the tools and aids that collect, reduce, organize, present, and transmit information for use in the planning and execution of operations. Executing and planning the full range of military operations in the current joint operations area requires unprecedented levels of information that can be trusted and acted on immediately. It is critical that the networked SoS be fully operational nearly 100% of the time so that decision makers have all of the information they need (without an overload of unnecessary information) in a timely manner to support the development and execution of proactive COAs designed to interrupt and/or outpace the adversary's decision cycle.

Evaluation strategies must include decision makers' cognitive performance in this kind of net-centric environment. Assurance that the networked SoS is providing the opportunity to keep a full level of situational understanding, an accurate battle space visualization through a current common operational picture, the ability to share that information with mission collaborators through effective and efficient collaboration tools, and the timely delivery of commander's intent are among the more critical capabilities for the networked SoS. However, the technological solution to providing those capabilities is not the only consideration; they must support the rapid OPTEMPO and unique ways in which warfighters wish to use the networked SoS to plan and execute missions. Evaluating these capabilities needs to occur in the same mission context and OPTEMPO as real-world operations to determine if the networked SoS is suitable for the users' needs.

2. Environment. In the section on internal factors, it was noted that an individual's state can affect the functioning of the prefrontal cortex, which is responsible for higher level cognitive functions (Wesensten, Belenky, and Balkin 2005). They expound on that by stating environmental conditions can cause sufficient degradation in an individual's physiological state to result in impaired functioning of the prefrontal cortex, and thus his or her ability to successfully execute tasks requiring higher levels of cognitive functioning, such as decision making.

With that understanding, it is important to evaluate the environmental conditions of a test environment for its potential to affect cognitive functioning because degrading that ability can cause the user of a networked SoS to improperly use it, perform poorly while using it, or revert to a more habitual method of executing a task that bypasses using the technology altogether.

3. Team. The Army is acquiring more complex manned and unmanned systems, of which many require more than one person to set up, calibrate, operate, monitor, and/or interact. The complexity of the systems may require one individual to attend to the system nearly 100% of the time, thus requiring other individuals to monitor the environment, send and receive sensor information, or conduct a variety of other tasks depending on the unit and mission. The ability of the team, which may be colocated or distributed, to collaborate and synchronize tasks requires the team to have complete understanding of what every other member of the team needs to accomplish and where each person is in the process (Cooke et al. 2000). Additionally, when the team understands the commander's intent, and they share a good mental model with the commander, team processes improve (Serfaty, Entin, and Johnston 1998). Members of the team are able to back one another up, anticipate what actions another member is about to take, and interpret cues that might indicate excessive overload or stress on a team member.

Requirements for systems, and especially networked SoS, typically do not identify the team processes that are necessary for employment. Evaluators, therefore, should be cognizant of this and establish derived measures to evaluate the ability of the systems or networked SoS to support not only individual collaboration, visualization, situational understanding, and information sharing needs, but also those of the team.

Summary

The intent of this article is not to prescribe specific test and evaluation strategies and measures, but to make the readers cognizant of the factors that have the potential to influence how users will use a networked SoS and how well the networked SoS can support the users' needs. While the Department of Defense does not directly procure warfighters, it does invest heavily in training, educating, and otherwise "making ready" warfighters to conduct missions to defend our country and promote peace around the world. As such, when we consider the capabilities we choose to procure for their use, we must consider not just the best technological solution, but the solution that best supports optimizing warfighters' performance, reducing demands on their already heavily taxed physical and cognitive abilities. Admittedly, designing test plans to examine these factors can be difficult, and certainly not all can be incorporated into an evaluation strategy. However, those systems or SoS that are being acquired to support higher order cognitive processes such as developing situational awareness, supporting collaborative processes, and visualizing the battle space should consider factors that shape the warfighters' abilities to do so. ❑

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