# *Systems Engineering in the Cognitive and Social Domains of NetCentric Operations*

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# So, Where Do We Go From Here?

*"Becoming net-centric is not about replacing the warfighter with technology. We will, for example, still need boots on the ground. Net-centric operations will allow humans to leverage information to better deal with unanticipated challenges, needs, partners, and circumstances."*

*"Enabling Technologies for Net-Centricity – Information on Demand", John Grimes (Department of Defense Chief Information Officer), CrossTalk, July 2007*

# Topics

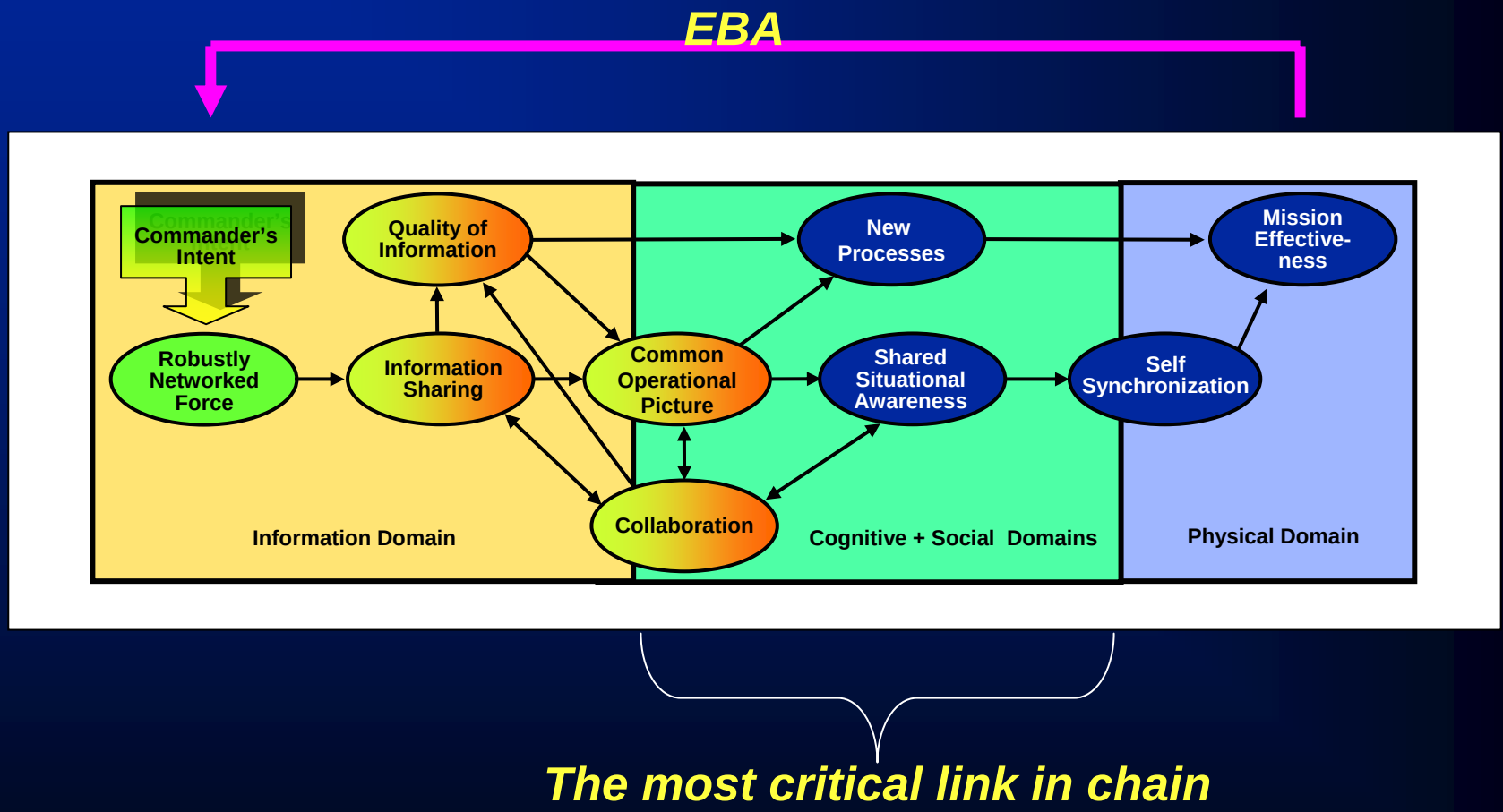
- NCO and Humans in the Loop (HITL)
- The Human As a Key Consideration in SoS
- Observations on Human Systems Integration (HSI)
- Implication from DOTMPLF on System Engineering
- Applying HSI
- Observation from the Perspective of Operations Analysts
- Considerations for Systems Engineering
- Observations on Experimentation
- Summary Comments on Engineering in the Cognitive and Social Domains

# Background

- **Net Centric Operations implies**
  - Leverage SoS in new and different ways
  - "Potential" for decision makers and operators to
    - Unprecedented access to information and assets over the network
    - More effective and efficient human "networking"
    - Does Faster information yield smarter decisions?
    - Leveraging ubiquitous and COI-specific services with pre-engineered interoperability in new and different ways
      - For the human this will require semantic interoperability; among many other interoperability attributes
- Bottom Line Goal >> "The DoD's NCE is a framework for human and technical connectivity and interoperability that allows DoD users and mission partners to share and protect information and to make informed decisions." *
- **Engineering for the Human –In-The-Loop (HITL) in a SoS**
  - Evolving area of research
    - But, implementation of SoS ahead of application of theory of networking over the SoS
      - e.g., in NCO - more sources, more deconfliction, more sensemaking required
    - Solution: Historically, engineer through experimentation
    - Dilemma: But what do we need to measure and for what purpose?

* "*DOD NetCentric Services Strategy:* Strategy for a Net-Centric, Service Oriented DoD Enterprise", DOD CIO, Washington, DC, May 4, 2007.

# NCO Value Chain




***The most critical link in chain***

# The Human As a Key Consideration in SoS

- Collaborative decision-making and shared situation awareness amongst the human operators. – key to SoS*
- More research in human system interaction and decision-making is required to understand better how to integrate these elements into an effective system-of-systems architecture.
  - Systems Engineering: human-machine interface (HMI) was the focus for a single system; human-to-system and human-to-human interaction is the focus for SoS
- Think of the OODA** Loop:
  - **How do we engineer a capability to improve the OODA without considering the HITL?**
  - **Clearly, the cognitive processes that allow the human to perceive and decide are at the center of the human dimensions of war**
  - **Remember: Capabilities are written in terms of what the human needs to accomplish , not what the machine must do**

* US AFSAB, Executive Summary and Annotated Brief, SAB-TR-05-04, July 2005
** OODA: observe, orient, decide, act

# The Human As a Key Consideration in SoS

- Including human system interaction as a part of System-of-Systems Engineering continues to be an important design parameter
- How do we design around the ad hoc, transaction-oriented situations that are common in military situations?
  - Many designs assume a fixed scenario as the basis for design ala DODAF
    - DODAF not sufficient for evaluation of “human behavior” utilizing information systems in a SoS environment
  - Systems are designed at the individual-to-system interface; in a SoS, NetCentric environment we should be designing to account for how individuals, crews, teams, units, or organizations interact with the systems, and in a context of a SoS

# Observations on HSI

- SOSE must be done in a context of users, operators, maintainers, and support personnel in operational environments which may complementary as well as have conflicting needs
  - Total ownership costs includes all of the above
  - Many do not want to consider all the above, since it may drive up total ownership costs of a proposed or envisioned SOS
  - Above and beyond the technology implementation of a single system we have the effects of security and safety (both driven by human behavior) multiplied – but, that is the value that SOSE brings to the table
- HSI ensures that human-centered domains are integrated throughout system design, development, manufacturing, operation, sustainment, and disposal
- HSI seeks to treat humans equally with other system elements, such as hardware and software, in system design

**INCOSE Handbook, 2007*

# Observations on HSI

- "Effective front-end analyses start with a thorough understanding of the mission of the new system, successes or problems with any predecessor systems, systems with which the proposed system must interface, and the knowledge, skills, abilities, and training associated with the people who are likely to interact with the proposed system." *
  - In addition, we must multiply the complexity of this analysis in a SoS
- There is controversy amongst the HSI discipline practitioners as to how HSI works in conjunction with SE (i.e., is it a separate discipline that comes in after SE or is an integrated discipline within SE?)

**INCOSE Handbook, 2007*

# Observations on HSI

- "Complexity is a reality in systems design and systems engineering and even more so in considering the multi-faceted human component considerations of a system" *
- The Challenge in the design of SoS:
  - Engineers will need to make all new systems "net-ready" for the net-centric environment, and capable of working with a wide array of existing and evolving systems
    - Each of which were optimized for different sets of human interactions with their respective systems, which may be at odds for cross-systems integration and use
    - Of critical importance is the ability to integrate and synthesize data from multiple systems and sources into useful information that can be employed by humans for effective decision making – i.e., the semantic interoperability problem

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# Implication from DOTMPLF on System Engineering

- NetCentric SoS implies breaking organizational barriers
- The key human element here is Trust
  - We must not only re-engineer our system to leverage NetCenricity, we must also re-engineer the enterprise
    - Will the system from organization A be there (availability and QoS) to support the system from organization B?
- Today – Mismatch between rate of applying technology to the problem versus the organizational and business implication of the transformation
  - All facets pf DOTMPLF must be re-evaluated when a new capability must be assessed against NetCentric principles

# Applying Human Systems Integration (HSI)

- Advances is practice of HSI are beginning to provide the capability to quantify and measure human characteristics. These newer methods also allow better decisions to be made early in the design and development process where changes are relatively inexpensive to make."[1]
  - Need: Greater focus on HITL as a measurable component of capability MOE and its implementation in SoS (systems + humans) MOP
  - Trend: Systems and products that can be operated and repaired by fewer people, by lesser skilled people, and/or people with lesser training will be in greater demand.
    - Manpower, personnel, and training (example: UAV and takeoff/landing expertise) are becoming key consideration in cost effectiveness and mission effectiveness
- Need to make the human component an "inherent part of the system," and the drive toward "quantification of people variables" in the overall system engineering of the system or SoS
  - In an era where "technology will solve the problem" it is a challenge for technologists to integrate the contributions of the soft sciences in the design of military systems that allow deterministic design solutions based on physics or bits/bytes.

[1] *"Handbook of Human Systems Integration", Harold Booher, Wiley & Sons, 2005*

# Applying Human Systems Integration (HSI)

- NetCentric SoS - The human is now taking an active and leading role in combining systems (and or services) to provide new capabilities (at run time versus at design time)
  - For the HITL today, this is art; depending on the COI and availability of new evolving services.
  - Can we bring science to this?
  - Passing Power to the Edge – implies new training paradigm with new SoS assets to configure and use.
  - Commanders are challenged to plan tasks in hours vs. days; planning in minutes versus hours
    - Paradigm shift: Less decision and information flow up and down the chain of command
    - Commander now "shepherds" or "monitors" versus "commands"
    - What is the minimum information required to make decisions at the Edge? – An area of intensive research and experimentation
  - How do we capture and analyze the impact of an operational architecture, and its complementary system architectures, when we are asked to accommodate responsive, agile, dynamic (on-the-fly changes to) operational approaches in a NetCentric environment?

# Applying Human Systems Integration (HSI)

- "….it can be expected that HSI activities will become more closely associated with constructive, virtual, and live simulations" [1]
  - Measurement of Human-in-the-loop parameters (primarily cognitive and social parameters) in the field has been problematic for SEs to define, apply, and measure
    - Not enough time and motion studies in battle as opposed to measuring business processes in a factory
  - Experimentation, in lieu of engineering, has been pursued
- Where can the contributions in decision theory help SE a SoS?
  - "Blink" >> What does this tell us?
    - Do people blindly look at and process data given to them by machines that will anticipate their needs?
    - What filters are on? >> varies from individual to individual
      - How can this be reproduced and designed to?
      - Is experimentation our only route to understanding?

[1] "Handbook of Human Systems Integration", Harold Booher, Wiley & Sons, 2005

# Observation from the Perspective of Operations Analysts[1]

- **Key challenge of SE of information systems is: How do we support decision making to improve mission effectiveness**
  - Decision making tasks
    - How much information is enough to make a decision?
    - The lower the tolerance for risk, the higher the demand for information to avoid that risk
    - Commanders process information differently, therefore, information must be shaped for the individual commander
  - Tasks do not always require quantifiable information
  - Just because something cannot be measured or quantified, doesn't mean it isn't important
    - Qualitative methods, such as observation, have their uses as well
  - Commanders must perform their tasks in a timely manner
    - Concern that they will wait for more or better information rather than act or make a decision
    - Need to balance the need for quick decision making with informed decision making

[1] Derived from: MORS Workshop Report: How Cognitive and Behavioral Factors Influence Command and Control, Military Operations Research Society, 22 April 2005

# Observation from the Perspective of Operations Analysts[1]

- On the Network - Email, phone, and chat proliferate workload irrespective of the chain of command
  - Increased capability may decrease effectiveness (e.g., more technology, information overload)
- Concern - In Network-Centric Warfare, everything depends on the network - What if it doesn't work?

[1] Derived from: MORS Workshop Report: How Cognitive and Behavioral Factors Influence Command and Control, Military Operations Research Society, 22 April 2005, p.22

# Considerations for Systems Engineering

- **System Engineering tradeoffs**
  - Drivers in the problem space
    - Changing nature of military operations (sectarian-based urban vs national armies
    - Call for certain cognitive and social behavior
      - e.g., each system optimized for human in system-specific domain; SoS human behavior subject of research
  - Requirements in terms of the human component of the architecture
    - As opposed to mission, task, or technology
      - Examples
        - Agility and adaptability refers to the human, rather than the command and control process
        - Distributed collaboration refers to the people who collaborate, rather than the tools used to collaborate
  - Technology can work well, but still not contribute to battlefield performance

# Considerations for Systems Engineering

- **Cognitive engineering (sometimes called cognitive systems engineering) is a multidisciplinary endeavor concerned with the analysis, design, and evaluation of complex systems of people and technology.**
  - It combines knowledge and experience from cognitive science, human factors, human-computer interaction design, and systems engineering.
  - focused on how people actually interact with complex technical systems
  - Human-computer interaction became a recognized field within computer science
  - That is, design must be based on the observation and understanding of system users "in the wild." *
  - The inherent systems approach of cognitive engineering means that the human user must be understood in the context of task, tools, and work environment.
  - In recent years, these approaches and methods have been applied to prevalent issues of information overload and sense making.

** Cognitive Engineering: Understanding Human Interaction with Complex Systems*
*John R. Gersh, Jennifer A. McKneely, and Roger W. Remington,*
*Johns Hopkins APL Technical Digest, Volume 26, Number 4 (2005)*

# Considerations for Systems Engineering

- On the network, the individual or group Goal-based performance is reached by facilitating information transmitting seamlessly as knowledge to the decision maker.
  - As such, the human needs be actively involved in information transformation by combining his/her experience with available information to generate useful knowledge.
    - Pushing information alone will not accomplish this
    - A fundamental tenet of Net Centricity is that it must be ubiquitously available on demand (available for pull).
    - Therefore, ultimate systems performance depends on the human element processing

# Observations on Experimentation

- "All too often designers are left with the choice of assessing human-system performance in expensive full-mission simulations or by estimating human capabilities from handbooks and guidelines. Neither approach has proven satisfactory. Increasingly, DoD and NASA sponsors have been supporting the development of computer simulation to explore joint human-system performance. In such simulations human behavioral characteristics are represented in a computer model of the operator."
- "the research loop from understanding basic human information processing to observing and analyzing technology developed in support of that understanding is intertwined with engineering and design primarily through the development of prototypes."
  - So the key research debate today is: Will measurement of human performance as a byproduct of mission (Live/Virtual/Constructive) exercises or modeling &simulation of human behavior provide the greatest feedback to effective system of systems design and orchestration in a SoS environment

** Cognitive Engineering: Understanding Human Interaction with Complex Systems*
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# Observations on Experimentation

Challenge of extracting meaningful data from experimentation with HITL:

- "Decision-making that is rule or algorithmically based can be modeled directly [Augmented Cognition], but error rates should be estimated if humans are involved in the relevant decision-making
  - Implications for SE: FMEA of technology based on effects of the HITL on Mission success
- Operational knowledge of human issues is still weak in many areas [of C2]. Systematic effort is required for organizing a consistent program for experiments on human issues."[1] [described in 2002 reference; still exists today]

[1] NATO Code of Best Practice for C² Assessment, CCRP, 2002

# Summary Comments on Engineering in the Cognitive and Social Domains

- **Observation and feedback**
  - HSI Cognitive and Social - expensive if done late in development of a system; experimentation and modeling needed at the SoS-level during CONOPS development
- **Stimulus/response analysis**
  - Paper simulation
  - War gaming
    - Concept exploration with instrumentation
- **Isolation of components of cognitive domain and social domains**
  - Use NetCentric Operations Conceptual Framework as a starting point

# Summary

- We need to provide systems and services to our warfighters quickly, but not without understanding how they are used both cognitively and socially on the battlefield
- This is broader than the Human Computer Interface (HCI) used in systems engineering today
- Just as bio-engineering revolutionized medicine, Cognitive Engineering and HSI as key considerations in systems engineering are, and will, revolutionize the conduct of war on both the strategic and tactical levels of warfare
- Learn more? Good references can be found in the INCOSE SE Handbook in the chapter on HSI

***We need to move from system-centered design to human-centered design***