A Conceptual Framework for Network Centric Warfare

Workshop on Network Centric Warfare and Network Enabled Capabilities
December 17-19, 2002

Ongoing Research Sponsored by OFT and ASD(C3I)
Agenda

• Informing Transformation
• The NCW Framework Initiative
• The NCW Framework
• Elements of the Force
• NCW Measures, Attributes, and Metrics
• Case Study: Air-to-Air Combat
• Summary and Next Steps
Informing Transformation

- NCW concepts are the military embodiment of Information Age concepts/technologies
- Early insights emerging – fundamental questions remain
  - Does NCW help make the force agile?
  - What is the best way to command and control a network-centric force?
  - How do we create a network-centric force?
  - How can we measure progress toward achieving a network-centric force?
- Requires a new theory and supporting body of knowledge
  - What experiments should we do?
  - What research is needed?
- Requires mechanism for development and application of theory by DoD and its allies
- Begins with a new conceptual framework and assessment methodology/tools

DoD transformation is, at its core, a military adaptation to the Information Age
DoD Priorities and Goals

• Priorities of the Office of Force Transformation in DoD
  – “Get the metrics right and applied enterprise wide”

• Desired Status in 5 Years Time
  – “Get the metrics right…”
    • Establish conceptual framework accompanied by mature theory and understanding of NCW
  – “…And applied enterprise wide”
    • Sufficient number of organizations throughout Government, academia, and industry with knowledge of the NCW Conceptual framework and the ability to apply it to solve real world problems
The NCW Framework Initiative
Key To Developing and Applying NCW Theory Across DoD Enterprise

Board of Directors

NCW Focused Research
NCW Knowledge Base
NCW Focused Experiments

Code of Best Practice
- Tools
- Methodology

NCW Theory (Hypotheses)
Conceptual Framework
Metrics
Relationships

NCW Theory

Awareness
Education
Consulting

Enterprise Applications
- Analysis
- Experiments
- Exercises
- Case Studies
- T & E
- Etc.

Board of Directors
Nature of NCW Conceptual Framework

• Based on current tenets of NCW
  – Potential new sources of combat power

• Includes key concepts and their
  – Measures
  – Attributes
  – Metrics
  – Relationships

• Provides basis for quantitative exploration/assessment
  – NCW hypotheses
  – Investment strategies
  – Other DOTML-PF related issues
NCW Framework Evolution

Tenets of NCW (DoD Report to Congress on Network Centric Warfare):

- A robustly networked force improves information sharing
- Information sharing and collaboration enhances the quality of information and shared situational awareness
- Shared situational awareness enables collaboration and self-synchronization, and enhances sustainability and speed of command
- These in turn dramatically increase mission effectiveness

NCW Foundation (1999)

NCW Conceptual Framework

- Quality of Organic Information
- Quality of Individual Information
- Quality of Individual Sensemaking
  - Awareness
  - Understanding
- Quality of Individual Decisions
- Quality of Collaborative Decisions
- Degree of Decision/Plan Synchronization
- Degree of Actions/Entities Synchronized
- Operating Environments
- Degree of Effectiveness/Agility
NCW Traverses Four Key Domains

Physical Domain
where strike, protect, and maneuver take place across different environments

Information Domain
where information is created, manipulated and shared

Cognitive Domain
where perceptions, awareness, beliefs, and values reside and where, as a result of sensemaking, decisions are made

Social Domain
where force entities interact
NCW Conceptual Framework

- Quality of Organic Information
- Quality of Individual Information
- Quality of Individual Sensemaking
- Quality of Individual Decisions
- Degree of Decision/ Plan Synchronization
- Degree of Action/ Entities Synchronized
- Operating Environments
- Degree of Effectiveness/ Agility

- Degree of Networking
- Degree of Information “Share-ability”
- Degree of Shared Information
- Degree of Shared Sensemaking
- Quality of Collaborative Decisions

- Force
- C2
- Effectors

- Information Sources
- Value Added Services

- Physical Domain
- Information Domain
- Cognitive Domain
- Social Domain
Key Elements: Nodes and Networks

**Force**

- **Sensors**
- **Networks**

<table>
<thead>
<tr>
<th>Command &amp; Control</th>
<th>Effectors (Shooters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>People</td>
<td>People</td>
</tr>
</tbody>
</table>

RAND 8/3/2004 Slide 11
Force

Measures for Key Elements

Mission Capability Packages

Elements (Network, Nodes)

Roles/Functions

Measures (Exogenous to the NCW framework)

- Phenomenology
- Coverage
- Persistence
- Performance
- Agility
- Service
- Capability
- Capacity
- Quality of Service
- Agility

Embedded in the NCW conceptual framework

- Effects
- Coverage
- Persistence
- Survivability
- Agility
NCW Conceptual Framework: Summary of Attributes (1)

### Quality of Organic Information

**Objective Measures**
- Correctness
- Consistency
- Currency
- Precision

**Fitness for Use**
- Completeness
- Accuracy
- Relevance
- Timeliness

### Quality of Individual Information

**Objective Measures**
- Correctness
- Consistency
- Currency
- Precision

**Fitness for Use**
- Completeness
- Accuracy
- Relevance
- Timeliness

### Degree of Networking

**Network**
- Reach
- Quality of Service
- Network Assurance
- Network Agility

**Net Ready Nodes**
- Capacity
- Connectivity
- P&R Capability Support
- Collaboration Support
- Node Assurance

### Degree of Information “Share-ability”

**Quality of Interactions**
- Quantity of Posted Info
- Quantity of Retrievable Info
- Ease of Use
Degree of Networking: Network
The extent to which force entities are interconnected

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reach</td>
<td>The degree to which force entities can connect and communicate</td>
</tr>
<tr>
<td>Quality of Service</td>
<td>Ability of network to provide a variety of communications and storage services</td>
</tr>
<tr>
<td>Network Assurance</td>
<td>Extent to which network provides services that facilitate the assurance of information in the areas of privacy, availability, integrity, authenticity, and nonrepudiation</td>
</tr>
<tr>
<td>Network Agility</td>
<td>Degree to which network can maintain quality of service in response to environmental changes (incorporates robustness, responsiveness, flexibility, innovativeness and adaptation)</td>
</tr>
</tbody>
</table>
### Degree of Networking: Network

The extent to which force entities are interconnected

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reach</td>
<td>Percent of nodes that can communicate in desired access modes, information formats, and applications</td>
</tr>
<tr>
<td>Quality of Service</td>
<td>Vector of performance metrics, including average bandwidth provided (available and bottleneck), packet delay, delay jitter, and data loss</td>
</tr>
<tr>
<td>Network Assurance</td>
<td>Categorical rating from “highly secure” to “not secure” (estimated from assessment of network’s installed security software, hardware, and usage policies)</td>
</tr>
<tr>
<td>Network Agility</td>
<td>See next slide</td>
</tr>
</tbody>
</table>
## Degree of Networking: Network Agility

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robustness</td>
<td>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.)</td>
</tr>
<tr>
<td></td>
<td>Effectiveness of network across varying levels of attack/degradation (baseline level determined by SME, simulation, analysis, empirical analysis, etc.)</td>
</tr>
<tr>
<td></td>
<td>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.)</td>
</tr>
<tr>
<td>Responsiveness</td>
<td>The timeliness of the response to an environmental change (baseline level determined by SME, simulation, analysis, empirical analysis, etc.)</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Number of options for responding to an environmental change&lt;br&gt;Compatibility of different responses (0=not compatible, 1=fully compatible; determined by SME, simulation, analysis, empirical analysis, etc.)</td>
</tr>
<tr>
<td>Innovativeness</td>
<td>Number of novel responses developed and implemented&lt;br&gt;(baseline determined by SME, simulation, analysis, empirical analysis, etc.)</td>
</tr>
<tr>
<td>Adaptiveness</td>
<td>Number and timeliness of changes to network structure and processes (baseline determined by SME, simulation, analysis, empirical analysis, etc.)</td>
</tr>
</tbody>
</table>
NCW Conceptual Framework: Summary of Attributes (2)

Degree of Information “Share-ability”

<table>
<thead>
<tr>
<th>Ease of Use</th>
<th>Quantity of Posted Info</th>
<th>Quantity of retrievable Info</th>
</tr>
</thead>
</table>

Quality of Individual Information

Objective Measures
- Correctness
- Consistency
- Accuracy
- Currency
- Precision

Fitness for Use
- Completeness
- Accuracy
- Relevance
- Timeliness

Quality of Individual Sensemaking: Awareness

Objective Measures
- Correctness
- Consistency
- Accuracy
- Currency
- Precision

Fitness for Use
- Completeness
- Accuracy
- Relevance
- Timeliness

Degree of Shared Information

Objective Measures
- Extent
- Quality
- Correctness
- Completeness
- Consistency
- Accuracy
- Currency
- Relevance
- Precision
- Timeliness

Degree of Shared Sensemaking: Shared Awareness

Objective Measures
- Extent
- Quality
- Correctness
- Completeness
- Consistency
- Accuracy
- Currency
- Timeliness
- Precision
- Uncertainty
Quality of Interactions: Dimensions and Attributes

The focus of interaction: share information, develop and share awareness, develop and share understandings, make decisions

Quality of Interactions
- Depth
- Breadth
- Intensity
- Agility

Individual Characteristics
- Risk Propensity
- Competence
- Trust
- Organizational Identification
- Confidence

Organizational and Individual Behaviors
- Cooperation
- Efficiency
- Synchronization
- Engagement
- Team vs. Task Balance

Organizational Characteristics
- Risk Propensity
- Competence
- Trust
- Confidence
- More ..
## Quality of Interactions

### Top Level Attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>Measures that describe the nature of the substance of interactions</td>
</tr>
<tr>
<td>Quantity</td>
<td>The quantity of information, awareness, understandings, and/or decisions that are the focus of interactions</td>
</tr>
<tr>
<td>Quality</td>
<td>The quality of information, awareness, understandings, and/or decisions that are the focus of the interactions</td>
</tr>
<tr>
<td>Breadth</td>
<td>Measures that describe the force entities that interact</td>
</tr>
<tr>
<td>Reach</td>
<td>The number of members that participate in the interactions</td>
</tr>
<tr>
<td>Selectivity</td>
<td>The ability to reach a selected sub-set</td>
</tr>
<tr>
<td>Intensity</td>
<td>Measures that describe the pace and completeness of interactions</td>
</tr>
<tr>
<td>Continuity</td>
<td>The persistence of the exchange among members (continuous to episodic)</td>
</tr>
<tr>
<td>Synchronicity</td>
<td>Type of interaction: synchronous or asynchronous in time and space</td>
</tr>
<tr>
<td>Mode</td>
<td>Degree to which all senses are involved (ranges from face to face with data + voice to voice or data only)</td>
</tr>
<tr>
<td>Latency</td>
<td>The time lag of interactions</td>
</tr>
<tr>
<td>Agility</td>
<td>Robustness, Flexibility, Responsiveness, Innovativeness, and Adaptability</td>
</tr>
</tbody>
</table>
Degree of Shared Sensemaking

• **Shared Awareness**- Those aspects of individual views of the battle space that are shared across two or more force entities/organizational members

• **Shared Understanding**- Those recognitions, including patterns, cause and effect relationships, dynamic futures, and opportunities and risks, that are shared across two or more force entities/organizational members
## Degree of Shared Sensemaking:
### Shared Awareness

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective Measures</td>
<td>Measures quality in reference to criteria that are independent of the situation</td>
</tr>
</tbody>
</table>
| Extent             | Proportion of awareness in common across force entities, within and across communities of interest (CoI)  
                     | Proportion of force entities that share a given awareness                  |
| Correctness        | Extent to which shared awareness is consistent with ground truth             |
| Consistency        | Extent to which shared awareness is consistent within and across CoI        |
| Currency           | Time lag of shared awareness                                                |
| Precision          | Level of granularity of shared awareness                                    |
| Quality            | Measures quality in reference to criteria that are determined by the situation |
| Completeness       | Extent to which relevant shared awareness is obtained                        |
| Accuracy           | Appropriateness of precision of shared awareness for a particular use       |
| Relevance          | Proportion of shared awareness obtained that is related to task at hand     |
| Timeliness         | Extent to which currency of shared awareness is suitable to its use         |
| Uncertainty        | Subjective assessment of confidence in shared awareness                    |
### NCW Conceptual Framework: Summary of Attributes (3)

#### Quality of Individual Sensemaking: Awareness

<table>
<thead>
<tr>
<th>Objective Measures</th>
<th>Fitness for Use</th>
<th>Quality of Interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctness</td>
<td>Completeness</td>
<td>Quantity</td>
</tr>
<tr>
<td>Consistency</td>
<td>Accuracy</td>
<td>Reach</td>
</tr>
<tr>
<td>Currency</td>
<td>Relevance</td>
<td>Intensity</td>
</tr>
<tr>
<td>Precision</td>
<td>Timeliness</td>
<td>Continuity</td>
</tr>
<tr>
<td></td>
<td>Uncertainty</td>
<td>Synchronicity</td>
</tr>
</tbody>
</table>

#### Quality of Individual Sensemaking: Understanding

<table>
<thead>
<tr>
<th>Objective Measures</th>
<th>Fitness for Use</th>
<th>Quality of Collaborative Decisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctness</td>
<td>Completeness</td>
<td>Fitness for Use</td>
</tr>
<tr>
<td>Consistency</td>
<td>Accuracy</td>
<td>Extent</td>
</tr>
<tr>
<td>Currency</td>
<td>Relevance</td>
<td>Consistency</td>
</tr>
<tr>
<td>Precision</td>
<td>Timeliness</td>
<td>Currency</td>
</tr>
</tbody>
</table>

#### Degree of Shared Sensemaking: Shared Awareness

<table>
<thead>
<tr>
<th>Objective Measures</th>
<th>Quality of Collaborative Decisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctness</td>
<td>Completeness</td>
</tr>
<tr>
<td>Consistency</td>
<td>Accuracy</td>
</tr>
<tr>
<td>Currency</td>
<td>Relevance</td>
</tr>
<tr>
<td>Precision</td>
<td>Timeliness</td>
</tr>
</tbody>
</table>

#### Degree of Shared Sensemaking: Shared Understanding

<table>
<thead>
<tr>
<th>Objective Measures</th>
<th>Quality of Collaborative Decisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctness</td>
<td>Completeness</td>
</tr>
<tr>
<td>Consistency</td>
<td>Accuracy</td>
</tr>
<tr>
<td>Currency</td>
<td>Relevance</td>
</tr>
<tr>
<td>Precision</td>
<td>Timeliness</td>
</tr>
</tbody>
</table>

#### Quality of Collaborative Decisions

<table>
<thead>
<tr>
<th>Objective Measures</th>
<th>Quality of Collaborative Decisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extent</td>
<td>Appropriate</td>
</tr>
<tr>
<td>Consistency</td>
<td>Accuracy</td>
</tr>
<tr>
<td>Currency</td>
<td>Relevance</td>
</tr>
<tr>
<td>Precision</td>
<td>Timeliness</td>
</tr>
</tbody>
</table>

### Individual Characteristics

- Agility
- Robustness
- Flexibility
- Selectivity
- Hardness
- Structure
- Size
- Confidence
- Permanence
- Autonomy
- Interdepend
- Interorganizational & Individual Behavior
- Engagement
- Efficiency
- Synchronization
- Adaptability
- Risk Propensity

### Organizational Characteristics

- Agility
- Robustness
- Flexibility
- Selectivity
- Hardness
- Structure
- Size
- Confidence
- Permanence
- Autonomy
- Interdepend
- Interorganizational & Individual Behavior
- Engagement
- Efficiency
- Synchronization
- Adaptability
- Risk Propensity

### Quality of Interactions

- Quality
- Reach
- Intensity
- Continuity
- Mode
- Robustness
- Flexible
- Innovative
- Adaptive
- Trust
- Confidence
- Competence
- Confidence
- Competence
- Confidence
- Hardness
- Permanence
- Structure
- Efficiency
- T vs. T

### Quality of Individual Decisions

- Mode of D. M.
- Selectivity
- Risk Propensity

### Degree of Shared Sensemaking: Shared Understanding

- Quality of Collaborative Decisions
- Mode of D. M.

### Objective Measures

- Correctness
- Accuracy
- Relevance
- Responsibility
- Timeliness
- Uncertainty

### Summary of Attributes (3)
<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective Measures</td>
<td>Measures quality in reference to criteria that are independent of the situation</td>
</tr>
<tr>
<td>Extent</td>
<td>Proportion of force entities that reach a collaborative decision</td>
</tr>
<tr>
<td>Consistency</td>
<td>Extent to which decisions are in agreement across force entities, within and across CoI</td>
</tr>
<tr>
<td>Currency</td>
<td>Time lag of decisions</td>
</tr>
<tr>
<td>Precision</td>
<td>Level of granularity of decisions</td>
</tr>
<tr>
<td>Fitness for Use Measures</td>
<td>Measures quality in reference to criteria that are determined by the situation</td>
</tr>
<tr>
<td>Appropriateness</td>
<td>Extent to which decisions are consistent with existing shared understanding, command intent and shared team values</td>
</tr>
<tr>
<td>Completeness</td>
<td>Extent to which relevant decisions encompass the necessary:</td>
</tr>
<tr>
<td></td>
<td>• Depth: range of actions and contingencies included</td>
</tr>
<tr>
<td></td>
<td>• Breadth: range of force elements included</td>
</tr>
<tr>
<td></td>
<td>• Time: range of time horizons included</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Appropriateness of precision of decisions for a particular use</td>
</tr>
<tr>
<td>Relevance</td>
<td>Proportion decisions that are important to the accomplishment of the task at hand</td>
</tr>
<tr>
<td>Timeliness</td>
<td>Extent to which currency of decision making is suitable to its use</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Inter-subjective assessment of confidence in decisions</td>
</tr>
<tr>
<td>Risk Propensity</td>
<td>Extent of risk aversion</td>
</tr>
<tr>
<td>Mode of Decision Making</td>
<td>Type of collaborative decision making structure utilized (authoritative decision making, consensus building, majority rule, etc.)</td>
</tr>
</tbody>
</table>
Quality of Collaborative Decisions II

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agility</td>
<td></td>
</tr>
<tr>
<td>Robustness</td>
<td>Degree to which collaborative decision is dominant across a range of situations and degradation conditions</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Degree to which collaborative decision reflects novel ways to perform known tasks and/or develops new ways of doing novel tasks</td>
</tr>
<tr>
<td>Responsiveness</td>
<td>Degree to which collaborative decision is relevant and timely</td>
</tr>
<tr>
<td>Innovativeness</td>
<td>Degree to which collaborative decision facilitates force entities’ ability to alter the decision, decision making participants and/or decision making process and implement appropriate modifications</td>
</tr>
<tr>
<td>Adaptability</td>
<td></td>
</tr>
</tbody>
</table>
NCW Conceptual Framework: Summary of Attributes (4)

Quality of Individual Decisions
- Fitness for Use
- Objective Measures
  - Appropriateness
  - Completeness
  - Consistency
  - Currency
  - Precision
  - Mode of D. M.
- Agility
  - Robustness
  - Flexibility
  - Responsiveness
  - Innovativeness
  - Adaptable
- Risk Propensity

Quality of Collaborative Decisions
- Fitness for Use
- Objective Measures
  - Appropriateness
  - Completeness
  - Consistency
  - Currency
  - Precision
  - Mode of D. M.
- Agility
  - Robustness
  - Flexibility
  - Responsiveness
  - Innovativeness
  - Adaptability

Degree of Decision/Plan Synchronization
- Synchronized Decisions/Plans

Degree of Actions/Entities Synchronized
- Synchronized Actions
- Synchronized Entities

Operating Environments

Degree of Effectiveness/Agility
- Achievement of Objectives
- Agility
- Timeliness
- Efficiency
Degree of Decisions and Actions Synchronized

Degree of Decisions / Plans Synchronized

• **Synchronized Decisions/Plans**: Proportion of decisions/plans that are conflicted, de-conflicted or synergistic

Degree of Actions / Entities Synchronized

• **Synchronized Actions**: Proportion of actions that are conflicted, de-conflicted or synergistic

• **Synchronized Entities**: Proportion of force entities whose positions are conflicted, de-conflicted, or synergistic
# Degree of Effectiveness / Agility

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achievement of Objectives</td>
<td>Degree to which Military/Strategic/ Political/ Social/ Economic/ Diplomatic objectives were achieved</td>
</tr>
<tr>
<td>Agility</td>
<td>The degree to which force entities were robust, flexible, responsive, innovative, and adaptable</td>
</tr>
<tr>
<td>Time</td>
<td>Time required to achieve objective</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Total cost of achieving objective</td>
</tr>
</tbody>
</table>
Framework: Attributes and Metrics

- Quality of Organic Information
- Quality of Individual Information
- Quality of Individual Sensemaking
- Quality of Individual Decisions
- Degree of Decision/Plan Synchronization
- Degree of Actions/Entities Synchronized
- Degree of Effectiveness/Agility
- Degree of Networking
- Degree of Information “Share-ability”
- Degree of Shared Information
- Degree of Shared Sensemaking
- Quality of Collaborative Decisions
- Operating Environments

Parts of framework for which attributes and metrics have been developed:

- Quality of Organic Information
- Quality of Individual Information
- Quality of Individual Sensemaking
- Quality of Individual Decisions
- Degree of Decision/Plan Synchronization
- Degree of Actions/Entities Synchronized
- Degree of Effectiveness/Agility

Parts of framework for which attributes have been developed:

- Quality of Organic Information
- Quality of Individual Information
- Quality of Individual Sensemaking
- Quality of Individual Decisions
- Degree of Decision/Plan Synchronization
- Degree of Actions/Entities Synchronized
- Degree of Effectiveness/Agility
Some Issues (1)

• Social Domain
  – Is this really a domain? If so, what is its relationship to the cognitive domain?

• Survivability
  – Are vulnerability and potential degradation of networked forces adequately accounted for in the framework?

• Synchronization
  – Should this measure explicitly account for asynchronization?

• Coherence
  – Should this be a separate measure? If so, how does it relate to synchronization?

• Force Cohesion
  – Is this an important indicator of mission success? How does it relate to degree of interaction?
Some Issues (2)

- Quality of Interactions
  - Are some of the attributes exogenous variables?

- Integration
  - Should this be an explicit measure?
  - How does it relate to degree of interaction?

- Agility
  - Is this measure adequately represented in the framework?
  - Should it be more systemic?

- Mission Capability Packages
  - Should the relationship between exogenous variables and DOTML-PF be more explicit?

- Operating Environment
  - Is its relationship to other measures proper?
  - What are the appropriate attributes?
Agenda

• Informing Transformation
• The NCW Framework Initiative
• The NCW Framework
• Elements of the Force
• NCW Measures, Attributes and Metrics

• Case Study: Air-to-Air Combat
• Summary and Next Steps
The JTIDS Operational Special Project
Results from 12,000 sorties in Air-to-Air Combat

• Conditions
  - AWACS with fighter aircraft
  - Range from 2 on 4 aircraft up to 8 on 16 aircraft missions
  - Day and night engagements
  - Voice only vs. voice + Link 16

• Results (Kill Ratio, X:1)

<table>
<thead>
<tr>
<th></th>
<th>Voice Only</th>
<th>Voice + Link 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>3.10</td>
<td>8.11</td>
</tr>
<tr>
<td>Night</td>
<td>3.62</td>
<td>9.40</td>
</tr>
</tbody>
</table>
Air-to-Air Scenario Exemplar
Four-on-Four Engagement

Blue11, 12

Red 1, 2

Red 3, 4

Blue13, 14

AWACS
Framework: Data Available for Case Study

Parts of Framework for which reasonable data is available

Parts of Framework for which data is currently unavailable

Quality of Organic Information

Quality of Individual Information

Quality of Individual Sensemaking

Quality of Individual Decisions

Degree of Networking

Degree of Information “Share-ability”

Degree of Shared Information

Degree of Shared Sensemaking

Quality of Interactions

Quality of Collaborative Decisions

Degree of Decision/Plan Synchronization

Degree of Actions/Entities Synchronized

Operating Environments

Degree of Effectiveness/Agility
**Force**

### Mission Capability Packages

#### Elements (Network, Nodes)

**Voice Only (MCP #1)**  
- AWACS
- Voice Network

**Voice + Link 16 (MCP #2)**  
- Data + Network
- Air Craft

#### Roles

- **Information Sources**
  - Detect/ID targets

- **Value added Services**
  - Fuse data
  - ID info
  - Distribute Info.

- **C2**
  - Assign aircraft to targets
  - Coordinate engagements

- **Effectors**
  - Kill Targets

### Functions

- **Voice Only (MCP #1)**  
  - Voice Network

- **Voice + Link 16 (MCP #2)**  
  - Data + Network

### Relevant Attributes

- **RExT**
- **ASDC3I**

- **Rand**
- **OFT**

- **8/3/2004 Slide 35**

- **Target Destruction**

- **Embedded in the NCW conceptual framework**
Influence of the Force on Quality of Organic Information

<table>
<thead>
<tr>
<th>Force</th>
<th>Information Sources</th>
<th>Value Added Services</th>
<th>C2</th>
<th>Effectors</th>
</tr>
</thead>
</table>

**Quality of Organic Information**

- Objective Measures
  - Correctness
  - Consistency
  - Currency
  - Precision

- Fitness for Use
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness

**Quality of Individual Information**

- Objective Measures
  - Correctness
  - Consistency
  - Currency
  - Precision

- Fitness for Use
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness

**Degree of Networking**

- Network
  - Reach
  - Quality of Service
  - Network Assurance
  - Network Agility

- Net Ready Nodes
  - Capacity
  - Connectivity
  - P&R Capability Support
  - Collaboration Support
  - Node Assurance

**Degree of Information “Share-ability”**

- Quantity of Posted Info
- Quantity of Retrievable Info
- Ease of Use

**Quality of Organic Information**

- Inference of the Force on Quality of Organic Information

- Influence of the Force on Quality of Organic Information

- Quality of Organic Information

- Quality of Individual Information

- Quality of Interactions

- Degree of Information “Share-ability”
Computing Quality of Organic Information

Sensor coverage
- Field of regard
- Instantaneous field of view
- Area coverage rate
- Revisit rate
  (e.g. AWACS 10 sec scan)
- Range
Probability of detection
  - $F_n$ of RCS
  - $F_n$ of doppler
Probability of false alarm
Probability of classification
Sighting location error
Sighting velocity error
Radar processor track precision

Quality of Organic Information

Objective Measures
- Correctness
- Consistency
- Currency
- Precision

Fitness for Use
- Completeness
- Accuracy
- Relevance
- Timeliness

Exogenous variables
- Environmental conditions
- Doctrine

Information Sources

Force

AWACs

AMTI radar
IFFN
NCTR#1
Etc.

Blue11
AMTI radar
IFFN
NCTR#1
Etc.

Blue12
AMTI radar
IFFN
NCTR#1
Etc.

Blue13
AMTI radar
IFFN
NCTR#1
Etc.

Blue14
AMTI radar
IFFN
NCTR#1
Etc.
Quality of Organic Information: Threat Tracks

Blue11, 12

 Completeness: Detection
 Correctness: ID

Blue13, 14

 Correctness: Location
 Correctness: Velocity
Comparing MCPs Using Summary Metrics

Quality of Organic Information

Degree of Information
"Share-ability"

Degree of Networking

Quality of Individual Information

Degree of Shared Information

Quality of Individual Sensemaking

Quality of Individual Decisions

Kill Ratio
(Synchronization / Effectiveness)

Overall average over information quality dimensions and package members
Comparing MCPs Using Summary Metrics
Synchronization and Effectiveness

Quality of Individual Information

Degree of Information
“Share-ability” 1.0

Degree of Networking

Quality of Organic Info

Kill Ratio
(Synchronization / Effectiveness)

Voice
Voice + Link 16

Overall average over information quality dimensions and package members
Quality of Sensemaking & Decisions
Relative Speed and Competitive Advantage

Hypotheses:

- Information sharing via Voice + Link 16 leads to less time necessary to gather critical information, which results in more time available for flight lead to develop sensemaking and make decisions.
- Information sharing via Voice + Link 16 leads to less time necessary for wingman to gather and monitor critical information, which results in opportunities for wingman to spend time sensemaking and making decisions.

B11 (Flight lead)

- **Voice Only**: Information → Awareness → Understanding → Decisions
- **Link-16 + Voice**: Info → Awareness → Understanding → Decisions

B12 (Wingman)

- **Voice Only**: Information → Awareness
- **Link-16 + Voice**: Info → Awareness → Understanding → Decisions
Degree of Synchronization and Effectiveness
Reported Tactical Improvements Enabled by Voice + Link 16

- **Voice + Link 16** allows greatly increased information sharing, leading to nearly-comprehensive awareness and understanding of air-to-air battlespace
- **Greater understanding** allows for use of four types of “high-awareness” tactics that lead to major increases in combat effectiveness

1. Increased numbers of engagements in the same time period

   ![Diagram 1. Increased numbers of engagements in the same time period](image)

2. Employment of the wingman as combatant rather than defensive patroller

   ![Diagram 2. Employment of the wingman](image)

3. Advance vectoring to engage red A/Cs from position of maximum advantage

   ![Diagram 3. Advance vectoring to engage red A/Cs](image)

4. Employment of cooperative formations to trap and destroy red A/Cs

   ![Diagram 4. Employment of cooperative formations](image)
Areas that Require Additional Attention for Air-to-Air Case Study

- Data describing cognitive and social behavior
  - Quality of interactions
  - Sensemaking / Decision making
- Impact of non-material changes in DOTML-PF
  - C2 concept (e.g., role of AWACs)
  - Changes in tactics, techniques and procedures
- Impact of changes in force mix
  - A/C, sensor and weapon type
- Effects of scaling number of A/C
  - Impact on net performance
  - Impact on mission effectiveness
- Accounting for dynamics over time
Agenda

• Informing Transformation
• The NCW Framework Initiative
• The NCW Framework
• Elements of the Force
• NCW Measures, Attributes and Metrics
• Case Study: Air-to-Air Combat

• Summary and Next Steps
Potential Next Steps

“Getting NCW Theory and Metrics Right…”
– Continue to refine and evolve the framework
– Complete Air-to-Air case study
  • Obtain additional data and address remaining measures
– Disseminate framework and obtain additional peer review

“…And Applied Enterprise-Wide”
– Engage potential users of framework to establish new opportunities for application
– Develop methodologies for applying framework in support of transformation
– Conduct broad range of case studies with key partners

Establish Board of Directors to shape priorities and ensure quality
Closing Thoughts

• We are making progress in developing/applying the framework
  - Well into definition of second generation framework
  - However, significant issues remain

• There is growing interest in applying the framework
  - Wide range of potential applications
  - Numerous opportunities for collaboration

• Important to keep up momentum
  - Refine/extend framework
  - Identify and enable key applications

• Broad community-wide participation is critical
Computing Quantity of Posted Info: Track Info over Voice Only

Information Sources

Value Added Services

Force

C2

Effectors

Degree of Networking

Net Ready Nodes

Capacity

Connectivity

P&R Capability Support

Collaboration Support

Node Assurance

Degree of Information

“Share-ability”

Quantity of Posted Info

Quantity of Retrievable Info

Ease of Use

Exogenous variables:

• Nodes: AWACS, F-15s
• Types: 4 red tracks, 5 blue tracks, etc.
• CONOPS, coding schemes, governing how to speak track info
• Red tracks have priorities, but two strike packages must know each other’s positions
• Track info “expires” after ten seconds

Computing Quantity of Posted Info:

• AWACS, F-15s can transmit over radio
• One military vocoder channel
• Assumed to be 100% in a benign environment
• No adjustments (static voice broadcasting network)

\[ f(\cdot) \]

• In this scenario, quantity of posted info equals quantity of retrievable info, except for probability of hearing voice
Computing Quantity of Posted Info:
Track Info over Link 16

Exogenous variables:
- Nodes: AWACS, F-15s
- Types: 4 red tracks, 5 blue tracks, etc.
- CONOPS, coding schemes, governing how to speak track info
- Red tracks have priorities, but two strike packages must know each other’s positions
- Track info “expires” after ten seconds

Networking:
- One shared Link 16 network (capacity greatly exceeds number of info items here)
- Assumed to be 100% in a benign environment
- No adjustments (static wireless network)

Ease of Use:
- In this scenario, quantity of posted info over Link 16 equals quantity of retrievable info
Computing Quantity of Posted Info:
Detailed Function for Posted Info

Exogenous variables:
- Number of nodes
- File sizes and number of files
- Variables impacting how quickly nodes can transmit pieces of information (CONOPS, coding schemes, etc.)
- Policies determining priority for posting
- Expiration age for each type of info objects
- Maximum queue lengths

\( f(\ldots) \): Vector for number of info objects that can be posted, by object type

**Phase 1. For each type of info object do:**
- If nodes can post object, do 2. Else, Num(type) = 0
- Use QoS parameters, network agility parameters, and exo variables to determine rate at which nodes can post info items of that type. Multiply this rate by probability of correct transmission, yielding *theoretical transmission rate*.

**Phase 2.**
- Use *theoretical rates* for each info type plus priority policies to determine what *fractions of postings* will be of each info type.
- Multiply *fractions of postings* times *theoretical rates* times *expiration age* to get Num(type) for each info type.

---

*Source/Sensors* | *Value Added Info Processors* | *C2* | *Effectors*
---|---|---|---

Degree of Networking
- **Network**
  - Reach
  - Quality of Service
  - Network Assurance
- **Network Agility**
- **Network Assurance**
- **P&R Capability Support**
- **Collaboration Support**
- **Node Assurance**
- **Capacity**
- **Connectivity**
- **Net Ready Nodes**

Degree of Information
- **“Share-ability”**
  - Quantity of Posted Info
  - Quantity of Retrievable Info
  - Ease of Use

---

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Computing Quantity of Posted Info: Detailed Function for Voice Only Network

Exogenous variables:
- Nodes: AWACS, F-15s
- Types: 4 red tracks, 5 blue tracks, etc.
- CONOPS, coding schemes, governing how to speak track info
- Red tracks have priorities, but two strike packages must know each other’s positions
- Track info “expires” after ten seconds

\[ f(\cdots) \text{: Vector for number of info objects that can be posted, by object type} \]

Phase 1. For each type of info object do:
- AWACS, F-15s can post (do 2)
- Using AF CONOPS and coding standards, AC can transmit three tracks every ten seconds on a military coding voice channel. In this scenario, this rate is unaffected by network assurance considerations.

Phase 2.
- Using AF priority policies, on average each 10-sec interval has two red tracks and one blue track.
- Since each track “lasts” for ten seconds, at most an average of two red tracks and one blue track can be posted at any time.

\[ f(\cdots) \text{: Vector for number of info objects that can be retrieved, by object type} \]
- 70% of voice tracks are audible, so metric is 0.7*Quantity of Posted Info
Computing Quantity of Posted Info: Detailed Function for Link 16 Network

Exogenous variables:
- Nodes: AWACS, F-15s
- Types: 4 red tracks, 5 blue tracks, etc.
- CONOPS, coding schemes, governing how to speak track info
- Red tracks have priorities, but two strike packages must know each other’s positions
- Track info “expires” after ten seconds

**Degree of Networking**
- Network
  - Reach
  - Quality of Service
  - Network Assurance
  - Network Agility
- Net Ready Nodes
  - Capacity
  - Connectivity
  - P&R Capability Support
  - Collaboration Support
  - Node Assurance

**F(…)**: Vector for number of info objects that can be posted, by object type

**Phase 1. For each type of info object, do:**
- AWACS, F-15s can post (do 2)
- Using Link 16 capacity and AF track coding standards, rate exceeds maximum number of tracks updated every second.

**Phase 2.**
- All tracks can be posted at least every second, so no priority policies apply.
- Info on all tracks can be updated every second, so info on all nine tracks can be posted at any given time.
Computing Correctness for Individual Information: Voice Only

Quality of Organic Information
- Objective Measures
  - Correctness
  - Consistency
  - Currency
  - Precision
- Fitness for Use
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness

Exogenous variables:
- Organic info assumed to be correct, within known margins of error
- Voice track messages only audible 70% of the time
- Military vocoder replicates hearing errors (no correction)

Quality of Individual Information
- Objective Measures
  - Correctness
  - Consistency
  - Currency
  - Precision
- Fitness for Use
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness

Degree of Information "Share-ability"
- Quantity of Posted Info
- Quantity of Retrievable Info
- Ease of Use

f(…)

Computing Correctness for Individual Information: Voice Only

Objective Measures Fitness for Use
- Correctness
- Completeness
- Accuracy
- Relevance
- Timeliness

Exogenous variables:
- Track, capability, intent information, all in standard formats
- No fusion performed
- Pilots will use organic information in preference to radio-reported information
- Pilots have sufficient training to use radio

Voice track messages only audible 70% of the time

Military vocoder replicates hearing errors (no correction)
Computing Correctness for Individual Information: Link 16

Quality of Organic Information

Objective Measures
- Correctness
- Consistency
- Currency
- Precision

Fitness for Use
- Completeness
- Accuracy
- Relevance
- Timeliness

Quality of Individual Information

Objective Measures
- Correctness
- Consistency
- Currency
- Precision

Fitness for Use
- Completeness
- Accuracy
- Relevance
- Timeliness

Exogenous variables:
- Organic info assumed to be correct, within known margins of error
- Assuming Link 16 reaches blue AC with no info degradation
- Display screen assumed to be error free within screen resolution

Degree of Information “Share-ability”
- Quantity of Posted Info
- Quantity of Retrievable Info
- Ease of Use

f(…)

- Objective Measures
- Fitness for Use
- Exogenous variables
- Degree of Information

- Organizational Voice
- General
Computing Correctness for Individual Information: Detailed Function

**Objective Measures**
- Correctness
- Consistency
- Currency
- Precision

**Fitness for Use**
- Completeness
- Accuracy
- Relevance
- Timeliness

**Quality of Individual Information**

**Quality of Organic Information**

**Degree of Information “Share-ability”**
- Quantity of Posted Info
- Quantity of Retrievable Info
- Ease of Use

**Exogenous variables:**
- Types of information
- Fusion performed on the information, and quality of this process
- Training to use retrieve and present information

**F(…): Correctness of information object**
- If info comes from an organic source, correctness = organic correctness
- If info is from network, correctness is the original correctness “multiplied” by the probability the info was retrieved and presented in original form.
- If info underwent fusion (esp. if taken from multiple sources), correctness is “multiplied” by additional factor representing fusion effectiveness.

- Whether the info was retrieved in original form
- Whether the presentation of the info introduces errors
Computing Correctness for Individual Information: Detailed Function, Voice Only

**Exogenous variables:**
- Track, capability, intent information, all in standard formats
- No fusion performed
- Pilots will use organic information in preference to radio-reported information
- Pilots have sufficient training to use radio

**F(…): Correctness of information object**
- Assumed correctness for each of blue AC’s own tracks
- If info received from vocoder, approximately a 70% chance that message will have been heard correctly
- Fusion does not apply in this case.

Total: 100% of organic info objects are correct; only 70% of voice-reported info objects are correct (others are garbled to point of unusability)

---

Objective Measures
- Correctness
- Consistency
- Currency
- Precision

Fitness for Use
- Completeness
- Accuracy
- Relevance
- Timeliness

Quality of Organic Information

Degree of Information “Share-ability”
- Quantity of Posted Info
- Quantity of Retrievable Info
- Ease of Use

Quality of Individual Information

---

Objective Measures
- Correctness
- Consistency
- Currency
- Precision

Fitness for Use
- Completeness
- Accuracy
- Relevance
- Timeliness

---

Voice

---
Computing Correctness for Individual Information: Detailed Function, Link 16

**Exogenous variables:**
- Track, capability, intent information, all in standard formats
- Fusion consolidates blue tracks only
- Pilots will use F-15 radar information in preference to AWACS information
- Pilots have sufficient training to use Link 16 display and radio

**F(…): Correctness of information object**
- Assumed correctness for each of blue AC’s own tracks
- No errors introduced by Link 16 or info display (and pilots adequately trained to use display)
Total: 100% of info objects are correct, whether organic or shared

**Objective Measures**
- Correctness
- Consistency
- Currency
- Precision

**Fitness for Use**
- Completeness
- Accuracy
- Relevance
- Timeliness

**Quality of Organic Information**

**Degree of Information “Share-ability”**

- Quantity of Posted Info
- Quantity of Retrievable Info
- Ease of Use

**Objective Measures**
- Correctness
- Consistency
- Currency
- Precision

**Fitness for Use**
- Completeness
- Accuracy
- Relevance
- Timeliness

**Quality of Individual Information**
Computing Extent of Shared Information: Detailed Function

Whether sender can communicate info with receiver

Whether sender and receiver are part of the same collaborative group

Number of communications “hops” between sender and receiver

Probability that sender will attempt to share information with receivers

Degree of Information “Share-ability”
- Quantity of Posted Info
- Quantity of Retrievable Info
- Ease of Use

Degree of Shared Information
Objective Measures
- Extent: Proportion of force entities that share information

Matrix showing probabilities that particular information elements have been shared with particular users
For each element of the matrix, Pr(shared) is the product of:
- the probability that the info is retrievable;
- the probability the sender and receiver are part of the same collaborative group;
- the probability the sender and receiver can communicate within the collaborative group;
- the probability the sender attempts to share the information with the receiver; and
- the probability the information is not degraded as a function of the number of “hops” between sender and receiver.
Quality of Individual Sensemaking and Decision Making: Timeliness (Qualitative)

F(…) : **Timeliness of Sensemaking / Decision Making**
- If information is shared among all participants, less time is spent gathering and validating information, improving the timeliness of sensemaking and decision making.
- Real-time interactions result in more efficient use of time, improving the timeliness of sensemaking and decision making.
- Flexible command structures allow force members to make decisions with fewer requirements, shortening decision-making times.

**Objective Measures**
- Correctness
- Consistency
- Currency
- Precision

**Quality of Individual Sensemaking: Awareness**
- Timeliness
- Uncertainty

**Quality of Individual Sensemaking: Understanding**
- Timeliness
- Uncertainty

**Quality of Interactions**
- Depth
  - Quantity
  - Reach
  - Continuity
  - Synchronicity
- Breadth
  - Quality
  - Selectivity
  - Latency
  - Mode
- Agility
  - Robustness
  - Flexible
- Exogenous variables: training, experience, etc.

**Quality of Individual Decisions**
- Appropriateness
- Completeness
- Accuracy
- Relevance
- Timeliness
- Uncertainty
- Risk Propensity

**Degree of Information “Share-ability”**
- Quantity of Posted Info
- Quantity of Retrievable Info
- Ease of Use

**Mode of D. M.**
- Trust
- Confidence
- Size
- Hardness
- Diversity
- Permanence
- Autonomy
- Structure
- Interdependence
- Organization & Ind. Behavior
- Efficiency
- Synchronization
- Engagement
- T vs. T

**Timeliness of Sensemaking / Decision Making**
- Whether all relevant members are participating
- Whether the intensity of the interactions matches the requirements of the mission
- Whether the command structure allows for flexible roles and distributed decision making

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Quality of Individual Sensemaking and Decision Making: Timeliness
Voice Only (Qualitative)

Quality of Individual Sensemaking: Awareness
- Fitness for Use
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness
  - Uncertainty

Quality of Individual Sensemaking: Understanding
- Fitness for Use
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness
  - Uncertainty

Quality of Individual Decisions
- Fitness for Use
  - Appropriateness
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness
  - Uncertainty
  - Risk Propensity
- Agility
  - Robustness
  - Flexibility
  - Responsiveness
  - Innovativeness
  - Adaptability

Degree of Information “Share-ability”
- Quantity of Posted Info
- Quantity of Retrievable Info
- Ease of Use

Exogenous variables: training, experience, etc.

F(...): Timeliness of Sensemaking / Decision Making
- Participants spend most of their time gathering and validating information from AWACS and other blue AC radars
- Voice communications adds delay over visual communications
- Inflexible command structures require a variety of explicit checks and permissions before engagement decisions can be made

- Whether the focus of interactions is on information gathering and validation or sensemaking/decision making
- The number of participants
- Whether the intensity of the interactions matches the requirements of the mission

- Whether the command structure allows for flexible roles and distributed decision making
Quality of Individual Sensemaking and Decision Making: Timeliness
Link 16 (Qualitative)

- **Quality of Individual Sensemaking: Awareness**
  - Objective Measures:
    - Correctness
    - Consistency
    - Currency
    - Precision
  - Fitness for Use:
    - Completeness
    - Accuracy
    - Relevance
    - Timeliness
    - Uncertainty

- **Quality of Individual Sensemaking: Understanding**
  - Objective Measures:
    - Correctness
    - Consistency
    - Currency
    - Precision
  - Fitness for Use:
    - Completeness
    - Accuracy
    - Relevance
    - Timeliness
    - Uncertainty

- **Quality of Interactions**
  - Depth:
    - Quantity
    - Reach
    - Continuity
    - Selection
    - Intensity
    - Latency
    - Mode
  - Agility:
    - Robustness
    - Flexible

- **Degree of Information “Share-ability”**
  - Quantity of Posted Info
  - Quantity of Retrieveable Info
  - Ease of Use
  - Exogenous variables: training, experience, etc.

- **Quality of Individual Decisions**
  - Objective Measures:
    - Consistency
    - Currency
    - Precision
  - Fitness for Use:
    - Appropriateness
    - Completeness
    - Accuracy
    - Relevance
    - Timeliness
    - Uncertainty
    - Risk Propensity
  - Agility:
    - Robustness
    - Flexibility
    - Responsiveness
    - Innovativeness
    - Adaptability

- **F(…)**: *Timeliness of Sensemaking / Decision Making*
  - Participants automatically receive all relevant information available from AWACS and other blue AC radars, so pilots incur no delays by communicating this information verbally.
  - Near-real time visual information displays are much faster than voice transmissions.
  - Flexible command structures allow pilots to engage targets, and support engaging pilots, directly. (Commanders only intervene when necessary.)

- **General**
  - The number of participants
  - Whether the intensity of the interactions matches the requirements of the mission
  - Whether the command structure allows for flexible roles and distributed decision making

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DEFINITIONS OF ATTRIBUTES
### Quality of Organic Information

Information gathered by individual sensors that is not shared and is unavailable to the network

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
<th>Attribute Summary (Click Here)</th>
<th>Metrics (Click Here)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective Measures</td>
<td>Measures quality in reference to criteria that are independent of the situation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correctness</td>
<td>Extent to which information is consistent with ground truth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consistency</td>
<td>Extent to which information is consistent with prior information</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Currency</td>
<td>Age of information</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precision</td>
<td>Level of measurement detail of information item</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fitness for Use</td>
<td>Measures quality in reference to criteria that are determined by the situation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completeness</td>
<td>Extent to which information relevant to ground truth is collected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>Appropriateness of precision of information for a particular use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relevance</td>
<td>Proportion of information collected that is related to task at hand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timeliness</td>
<td>Extent to which currency of information is suitable to its use</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Degree of Information “Share-ability”

The degree to which information could be shared among force entities

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity of Posted Information</td>
<td>Extent to which collected information is posted</td>
</tr>
<tr>
<td>Quantity of Retrievable Information</td>
<td>Proportion of nodes that can retrieve various sets of information. Determined by the following:</td>
</tr>
<tr>
<td></td>
<td>• Awareness of Information: Degree to which the existence of the information is advertised to force member</td>
</tr>
<tr>
<td></td>
<td>• Access to Information: Degree to which access to information is controlled</td>
</tr>
<tr>
<td></td>
<td>• Meta-data of Information: Degree to which information has labels describing what it is and how it may be used (facilitates indexing and searching)</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>Degree to which presentation of information facilitates desired use</td>
</tr>
</tbody>
</table>
# Quality of Individual Information

Information gathered by individuals from the network and organic sources

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
<th>Attribute Summary</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective Measures</td>
<td>Measures quality in reference to criteria that are independent of the situation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correctness</td>
<td>Extent to which information is consistent with ground truth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consistency</td>
<td>Extent to which information is internally consistent with prior information/ awareness / understanding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Currency</td>
<td>Age of information</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precision</td>
<td>Level of measurement detail of information item</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fitness for Use Measures</td>
<td>Measures quality in reference to criteria that are determined by the situation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completeness</td>
<td>Extent to which information relevant to ground truth is obtained</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>Appropriateness of precision of information for a particular use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relevance</td>
<td>Proportion of information retrieved that is related to task at hand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timeliness</td>
<td>Extent to which currency of information is suitable to its use</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Quality of Individual Sensemaking

**Awareness**- An individual’s holistic view of the battlespace that includes mission constraints, environment, time space relationships, the capabilities and intentions of red, blue, and neutral forces and an assessment of the associated uncertainties.

**Understanding**- An individual’s recognition of patterns, cause and effect relationships, dynamic futures, and opportunities and risks.
Quality of Individual Sensemaking: Awareness

<table>
<thead>
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<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective Measures</strong></td>
<td>Measures quality in reference to criteria that are independent of the situation</td>
</tr>
<tr>
<td>Correctness</td>
<td>Extent to which awareness is consistent with ground truth</td>
</tr>
<tr>
<td>Consistency</td>
<td>Extent to which awareness is internally consistent with prior awareness</td>
</tr>
<tr>
<td>Currency</td>
<td>Time lag of awareness</td>
</tr>
<tr>
<td>Precision</td>
<td>Level of granularity of awareness</td>
</tr>
<tr>
<td><strong>Fitness for Use Measures</strong></td>
<td>Measures quality in reference to criteria that are determined by the situation</td>
</tr>
<tr>
<td>Completeness</td>
<td>Extent to which relevant awareness is obtained</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Appropriateness of precision of awareness for a particular use</td>
</tr>
<tr>
<td>Relevance</td>
<td>Proportion of awareness obtained that is related to task at hand</td>
</tr>
<tr>
<td>Timeliness</td>
<td>Extent to which currency of awareness is suitable to its use</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Subjective assessment of confidence in awareness</td>
</tr>
</tbody>
</table>
# Quality of Individual Sensemaking: Understanding

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective Measures</strong></td>
<td>Measures quality in reference to criteria that are independent of the situation</td>
</tr>
<tr>
<td>Correctness</td>
<td>Extent to which understanding is consistent with ground truth</td>
</tr>
<tr>
<td>Consistency</td>
<td>Extent to which understanding is internally consistent with prior understanding</td>
</tr>
<tr>
<td>Currency</td>
<td>Time lag of understanding</td>
</tr>
<tr>
<td>Precision</td>
<td>Level of granularity of understanding</td>
</tr>
<tr>
<td><strong>Fitness for Use Measures</strong></td>
<td>Measures quality in reference to criteria that are determined by the situation</td>
</tr>
<tr>
<td>Completeness</td>
<td>Extent to which relevant understanding is obtained</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Appropriateness of precision of understanding for a particular use</td>
</tr>
<tr>
<td>Relevance</td>
<td>Proportion of understanding obtained by force member that is related to task at hand</td>
</tr>
<tr>
<td>Timeliness</td>
<td>Extent to which currency of understanding is suitable to its use</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Subjective assessment of confidence in understanding</td>
</tr>
</tbody>
</table>
## Quality of Individual Decisions I

The extent to which an individual’s decisions build upon awareness and understanding

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<tbody>
<tr>
<td><strong>Objective Measures</strong></td>
<td>Measures quality in reference to criteria that are independent of the situation</td>
</tr>
<tr>
<td>Consistency</td>
<td>Extent to which decisions are internally consistent with prior understanding and decisions</td>
</tr>
<tr>
<td>Currency</td>
<td>Time lag of decisions</td>
</tr>
<tr>
<td>Precision</td>
<td>Level of granularity of decisions</td>
</tr>
<tr>
<td><strong>Fitness for Use Measures</strong></td>
<td>Measures quality in reference to criteria that are determined by the situation</td>
</tr>
<tr>
<td>Appropriateness</td>
<td>Extent to which decisions are consistent with existing understanding, command intent and values</td>
</tr>
<tr>
<td>Completeness</td>
<td>Extent to which relevant decisions encompass the necessary:</td>
</tr>
<tr>
<td></td>
<td>• Depth: range of actions and contingencies included</td>
</tr>
<tr>
<td></td>
<td>• Breadth: range of force elements included</td>
</tr>
<tr>
<td></td>
<td>• Time: range of time horizons included</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Appropriateness of precision of decisions for a particular use</td>
</tr>
<tr>
<td>Relevance</td>
<td>Proportion of decisions that are significant to task at hand</td>
</tr>
<tr>
<td>Timeliness</td>
<td>Extent to which currency of decision making is suitable to its use</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Subjective assessment of confidence in decisions</td>
</tr>
<tr>
<td>Risk Propensity</td>
<td>Extent of risk aversion</td>
</tr>
<tr>
<td><strong>Mode of Decision Making</strong></td>
<td>Type of decision making process utilized (naturalistic, dominated, min-max, expected utility)</td>
</tr>
</tbody>
</table>
## Quality of Individual Decisions II

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agility</td>
<td></td>
</tr>
<tr>
<td>Robustness</td>
<td>Degree to which decision is dominant across a range of situations and degradation conditions</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Degree to which decision allows force entities to maintain flexibility (i.e., incorporates multiple ways of succeeding)</td>
</tr>
<tr>
<td>Responsiveness</td>
<td>Degree to which decision is relevant and timely</td>
</tr>
<tr>
<td>Innovativeness</td>
<td>Degree to which decision reflects novel ways to perform known tasks and/or develops new ways of doing novel tasks</td>
</tr>
<tr>
<td>Adaptability</td>
<td>Degree to which decision facilitates force entities’ ability to alter the decision, decision making participants and/or decision making process and implement appropriate modifications</td>
</tr>
</tbody>
</table>
Quality of Interactions: Definitions and Explanations

- Interactions involve force entities actively sharing information, and developing awareness, understanding and/or making decisions (developing plans) in a collaborative fashion while working together toward a common purpose.
- The focus of interactions: information sharing, developing and sharing awareness, developing and sharing understandings, making decisions.
- Attributes of interactions:
  - Depth, breadth, intensity, agility.
- Contributing attributes:
  - Individual Characteristics: risk propensity, competence, trust, organizational identification, confidence.
  - Organizational Characteristics: risk propensity, competence, trust, confidence, size, hardness, diversity, permanence, autonomy, structure, interdependence.
  - Organizational & Individual Behaviors: cooperation, efficiency, synchronization, engagement, team vs. task balance.
# Quality of Interactions

## Contributing Attributes: Individual Characteristics

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Propensity</td>
<td>Extent of risk aversion</td>
</tr>
<tr>
<td>Competence</td>
<td>Level of knowledge, skills, abilities, and attitudes (KSAAAs)</td>
</tr>
<tr>
<td>Trust</td>
<td>Extent to which individual is willing to rely on other members</td>
</tr>
<tr>
<td>Organizational Identification</td>
<td>Extent to which individual’s identities align with organizational identities</td>
</tr>
<tr>
<td>Confidence</td>
<td>Degree of individual’s expectation that other members are reliable</td>
</tr>
</tbody>
</table>
## Quality of Interactions

### Contributing Attributes: Organizational Characteristics

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Propensity</td>
<td>Extent of risk aversion</td>
</tr>
<tr>
<td>Competence</td>
<td>Distribution of members knowledge, skills, abilities and attitudes (KSAAs)</td>
</tr>
<tr>
<td>Trust</td>
<td>Extent to which members are willing to rely on one another</td>
</tr>
<tr>
<td>Confidence</td>
<td>Extent to which members have expectations of the reliability of the organization</td>
</tr>
<tr>
<td>Size</td>
<td>Number of team members involved</td>
</tr>
<tr>
<td>Hardness</td>
<td>Degree to which team members have interacted in the past on the same task</td>
</tr>
<tr>
<td>Diversity</td>
<td>Degree to which team members are heterogeneous or homogeneous across exogenous variables: experience, age, gender, etc.</td>
</tr>
<tr>
<td>Permanence</td>
<td>Expected duration of organization</td>
</tr>
<tr>
<td>Autonomy</td>
<td>Extent to which organization is externally or self directed</td>
</tr>
<tr>
<td>Structure</td>
<td>Distribution of peer and authority relationships</td>
</tr>
<tr>
<td></td>
<td>• Layers of authority</td>
</tr>
<tr>
<td></td>
<td>• Functional Differentiation</td>
</tr>
<tr>
<td></td>
<td>• Connectedness within and across layers</td>
</tr>
<tr>
<td></td>
<td>• Directness of connections</td>
</tr>
<tr>
<td>Interdependence</td>
<td>Extent to which members depend on one another for resources (materials, KSAAs, etc.)</td>
</tr>
</tbody>
</table>
Quality of Interactions
Contributing Attributes:
Organizational and Individual Behaviors

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Extent to which member(s) are willing and able to work together</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Extent to which members utilize one another’s resources so as to minimize costs and maximize benefits</td>
</tr>
<tr>
<td>Synchronization</td>
<td>Extent to which organization is conflicted, deconflicted, or synergistic</td>
</tr>
<tr>
<td>Engagement</td>
<td>Extent to which all members actively and continuously participate</td>
</tr>
<tr>
<td>Team vs. Task Balance</td>
<td>Extent to which efforts are directed to organizational issues vs. relating to the objective</td>
</tr>
</tbody>
</table>
## Degree of Shared Information

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective Measures</td>
<td>Measures quality in reference to criteria that are independent of the situation</td>
</tr>
<tr>
<td>Extent</td>
<td>Proportion of information in common across force entities, within and across communities of interest (CoI)</td>
</tr>
<tr>
<td>Correctness</td>
<td>Extent to which shared information is consistent with ground truth</td>
</tr>
<tr>
<td>Consistency</td>
<td>Extent to which shared information is consistent within and across CoI</td>
</tr>
<tr>
<td>Currency</td>
<td>Age of shared information</td>
</tr>
<tr>
<td>Precision</td>
<td>Level of measurement detail of shared information item</td>
</tr>
<tr>
<td>Quality</td>
<td>Measures quality in reference to criteria that are determined by the situation</td>
</tr>
<tr>
<td>Completeness</td>
<td>Extent to which shared information relevant to ground truth is obtained</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Appropriateness of precision of shared information for a particular use</td>
</tr>
<tr>
<td>Relevance</td>
<td>Proportion of shared information retrieved that is related to task at hand</td>
</tr>
<tr>
<td>Timeliness</td>
<td>Extent to which currency of shared information is suitable to its use</td>
</tr>
</tbody>
</table>
## Degree of Shared Sensemaking: Shared Understanding

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective Measures</strong></td>
<td>Measures quality in reference to criteria that are independent of the situation</td>
</tr>
<tr>
<td>Extent</td>
<td>Proportion of understanding in common across force entities, within and across communities of interest (CoI) Proportion of force entities that share a given understanding</td>
</tr>
<tr>
<td>Correctness</td>
<td>Extent to which shared understanding is consistent with ground truth</td>
</tr>
<tr>
<td>Consistency</td>
<td>Extent to which shared understanding is consistent within and across CoI</td>
</tr>
<tr>
<td>Currency</td>
<td>Time lag of shared understanding</td>
</tr>
<tr>
<td>Precision</td>
<td>Level of granularity of shared understanding</td>
</tr>
<tr>
<td><strong>Quality</strong></td>
<td>Measures quality in reference to criteria that are determined by the situation</td>
</tr>
<tr>
<td>Completeness</td>
<td>Extent to which relevant shared understanding is obtained</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Appropriateness of precision of shared understanding for a particular use</td>
</tr>
<tr>
<td>Relevance</td>
<td>Proportion of shared understanding that is related to task at hand</td>
</tr>
<tr>
<td>Timeliness</td>
<td>Extent to which currency of shared understanding is suitable to its use</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Subjective assessment of confidence in shared understanding</td>
</tr>
</tbody>
</table>
DEFINITION OF METRICS
# Quality of Organic Information

Information gathered by individual sensors that is not shared and is unavailable to the network

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective Measures</strong></td>
<td>Measures quality in reference to criteria that are independent of the situation</td>
</tr>
<tr>
<td>Correctness</td>
<td>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.)</td>
</tr>
<tr>
<td>Consistency</td>
<td>Degree of ‘deviation’ from previous information</td>
</tr>
<tr>
<td>Currency</td>
<td>Age of information</td>
</tr>
<tr>
<td>Precision</td>
<td>Level of measurement detail of information item</td>
</tr>
<tr>
<td><strong>Fitness for Use Measures</strong></td>
<td>Measures quality in reference to criteria that are determined by the situation</td>
</tr>
<tr>
<td>Completeness</td>
<td>Percentage of ground truth relevant and needed information collected</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Degree to which precision matches what is needed (0=no match, 10=high degree of matching between precision level needed and available)</td>
</tr>
<tr>
<td>Relevance</td>
<td>Proportion of information collected that is related to task at hand</td>
</tr>
<tr>
<td>Timeliness</td>
<td>Degree to which currency matches what is needed (0=no match, 10=high degree of matching between currency level needed and available)</td>
</tr>
</tbody>
</table>
**Degree of Information “Share-ability”**

The degree to which information could be shared among force entities

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Metrics</th>
<th>Attribute Summary (Click Here)</th>
<th>Definitions (Click Here)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity of Posted Information</td>
<td>Percent of collected information posted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity of Retrievable Information</td>
<td>Percentage of nodes that can retrieve various sets of information.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Use</td>
<td>Degree to which information is easy to use (0=low degree of ease of use, 10=high degree of ease of use)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Quality of Individual Information

Information gathered by individuals from the network and organic sources

<table>
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<td>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, etc.)</td>
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<tr>
<td>Consistency</td>
<td>Degree of ‘deviation’ from previous information</td>
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<tr>
<td>Currency</td>
<td>Age of information</td>
</tr>
<tr>
<td>Precision</td>
<td>Level of measurement detail of information item</td>
</tr>
<tr>
<td>Fitness for Use Measures</td>
<td>Measures quality in reference to criteria that are determined by the situation</td>
</tr>
<tr>
<td>Completeness</td>
<td>Percentage of ground truth relevant and needed information</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Degree to which precision matches what is needed (0=no match, 10=high degree of matching between precision)</td>
</tr>
<tr>
<td>Relevance</td>
<td>Proportion of information that is related to task at hand</td>
</tr>
<tr>
<td>Timeliness</td>
<td>Degree to which currency matches what is needed (0=no match, 10=high degree of matching between currency level needed and available)</td>
</tr>
</tbody>
</table>
## Quality of Individual Sensemaking: Awareness

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Metrics</th>
<th>Definitions</th>
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</thead>
<tbody>
<tr>
<td>Objective Measures</td>
<td>Measures quality in reference to criteria that are independent of the situation</td>
<td>(Click Here)</td>
</tr>
<tr>
<td>Correctness</td>
<td>Correspondence with ground truth-correlation coefficient (0= no convergence, 1= full convergence between individual’s awareness and ground truth)</td>
<td>(Click Here)</td>
</tr>
<tr>
<td>Consistency</td>
<td>Degree of ‘deviation’ from awareness gained from previous time period</td>
<td>(Click Here)</td>
</tr>
<tr>
<td>Currency</td>
<td>Time lag of awareness</td>
<td>(Click Here)</td>
</tr>
<tr>
<td>Precision</td>
<td>Level of granularity of awareness</td>
<td>(Click Here)</td>
</tr>
<tr>
<td>Fitness for Use Measures</td>
<td>Measures quality in reference to criteria that are determined by the situation</td>
<td>(Click Here)</td>
</tr>
<tr>
<td>Completeness</td>
<td>Percentage of ground truth picture included in awareness</td>
<td>(Click Here)</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Degree to which precision matches what is needed (0=no match, 10=high degree of matching between precision level needed and available)</td>
<td>(Click Here)</td>
</tr>
<tr>
<td>Relevance</td>
<td>Proportion of awareness that is related to task at hand</td>
<td>(Click Here)</td>
</tr>
<tr>
<td>Timeliness</td>
<td>Degree to which currency matches what is needed (0=no match, 10=high degree of matching between currency level needed and available)</td>
<td>(Click Here)</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Confidence level (0%=uncertain, 100%= certain) or confidence interval (95%, 90%, etc.) of awareness</td>
<td>(Click Here)</td>
</tr>
</tbody>
</table>
# Quality of Individual Sensemaking: Understanding

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Metrics</th>
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<th>Definitions (Click Here)</th>
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<td></td>
</tr>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>Consistency</td>
<td>Degree of ‘deviation’ from understanding gained from previous time period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Currency</td>
<td>Time lag of understanding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precision</td>
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<td></td>
</tr>
<tr>
<td><strong>Fitness for Use Measures</strong></td>
<td>Measures quality in reference to criteria that are determined by the situation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completeness</td>
<td>Percentage of ground truth picture included in understanding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>Degree to which precision matches what is needed (0=no match, 10=high degree of matching between precision level needed and available)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relevance</td>
<td>Proportion of understanding that is related to task at hand</td>
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<td></td>
</tr>
<tr>
<td>Timeliness</td>
<td>Degree to which currency matches what is needed (0=no match, 10=high degree of matching between currency level needed and available)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Confidence level (0% =uncertain, 100%= certain) or confidence interval (95%, 90%, etc.) of awareness</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The NCW Framework Initiative
Key To Developing and Applying NCW Theory Across DoD Enterprise

Board of Directors

NCW Focused Research

NCW Knowledge Base

NCW Focused Experiments

Code of Best Practice
- Tools
- Methodology

NCW Theory (Hypotheses)
- Conceptual Framework
- Metrics
- Relationships

Awareness
- Education
- Consulting

Enterprise Applications
- Analysis
- Experiments
- Exercises
- Case Studies
- T & E
- Etc.

• Analysis
• Experiments
• Exercises
• Case Studies
• T & E
• Etc.
Status of Framework Development

• “Getting NCW Theory and Metrics Right…”
  – Where we are
    • Second generation framework
      – Being evolved through peer review
    • Initial case study in progress (Air-to-Air combat)
  – Where we are going
    • Additional peer review
    • Continual revision

• “…And Applied Enterprise-Wide”
  – Where we are
    • Establishing collaborative partnerships
  – Where we are going
    • Dissemination and education
      – Symposium, workshop, web, brochure, tutorials
    • Additional case studies
      – Sponsored, supported, encouraged
Application of the NCW Framework to Air-to-Air Combat

- **Objectives**
  - Gain insight into how NCW is a new source of power in Air-to-Air combat
  - Illuminate contribution of enabling capabilities in the NCW value chain
  - Identify areas where data is needed
  - Assess utility of framework and identify needed improvements

- **Approach**
  - Start with data from the JTIDS Operational Special Project
  - Apply NCW Framework to instantiate influence model
  - Capitalize on additional data and impute missing data
  - Identify sources of improved combat power
Numerical Metrics for Case Study
Calculated with Analytica

Here, we assign targeting-level info to have a value of 1, and cue-only-level info to have a value of 0.25.

Definition:
\[
\text{avg}(\max(Q_{\text{of individual info}} \times \text{Time to use weights}, Time to use levels) \times Ei_{\text{red or blue}}, \text{EEl}) / \sum(Ei_{\text{red or blue}}, \text{EEl})
\]

Inputs:
- Ei\(1\)
- Ei\(2\)
- Ei\(_{\text{red or blue}}\)
- Q_{\text{of individual info}}
- Time to use levels
- Time to use weights
NCW Conceptual Framework

Quality of Organic Information

Quality of Individual Information

Quality of Individual Sensemaking Awareness Understanding

Quality of Individual Decisions

Degree of Decision/ Plan Synchronization

Degree of Actions/ Entities Synchronized

Operating Environments

Degree of Effectiveness/ Agility
Quality of Organic Information: Blue Tracks

$Q_1^B$: Completeness: Detection

$Q_2^B$: Correctness: ID

$Q_3^B$: Correctness: Location

$Q_4^B$: Correctness: Velocity
### Influence of Networking on Information "Share-ability"

#### Quality of Organic Information

<table>
<thead>
<tr>
<th>Objective Measures</th>
<th>Fitness for Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctness</td>
<td>Completeness</td>
</tr>
<tr>
<td>Consistency</td>
<td>Accuracy</td>
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<td>Currency</td>
<td>Relevance</td>
</tr>
<tr>
<td>Precision</td>
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#### Quality of Individual Information

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</tbody>
</table>

#### Degree of Networking

- **Network**
  - Reach
  - Quality of Service
  - Network Assurance
  - Network Agility

- **Net Ready Nodes**
  - Capacity
  - Connectivity
  - P&R Capability Support
  - Collaboration Support
  - Node Assurance

#### Degree of Information "Share-ability"

- Quantity of Posted Info
- Quantity of Retrievable Info
- Ease of Use
Computing Quantity of Posted Info

**Degree of Networking**
- Network
  - Reach
  - Quality of Service
  - Network Assurance
  - Network Agility

**Degree of Information “Share-ability”**
- Quantity of Posted Info
- Quantity of Retrievable Info
- Ease of Use

**Exogenous variables:**
- Number of nodes
- Number and size of files
- Variables that impact how quickly nodes can transmit (CONOPS, coding schemes, etc.)
- Policies determining priority for posting
- Expiration age for each type of info objects
- Maximum queue lengths

In this scenario, quantity of posted info. equals quantity of retrievable info, _except_ for probability of hearing voice.

Whether nodes can transmit to network
Posting channel numbers, types, and bandwidth (for data links only)
Prob of correct transmission
Adjustments to probability that QoS will be delivered

Voice Only  Link 16
Quantity of Retrieved Information
Percent of Organic Information Retrieved

Voice Only

<table>
<thead>
<tr>
<th>Threat Tracks</th>
<th>Blue Tracks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q₁</td>
<td>Q₂</td>
</tr>
<tr>
<td>0.75</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Link 16 + Voice

<table>
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<th>Threat Tracks</th>
<th>Blue Tracks</th>
</tr>
</thead>
<tbody>
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<td>Q₁</td>
<td>Q₂</td>
</tr>
<tr>
<td>0.75</td>
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</tbody>
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Completeness: Detection
Correctness: ID
Correctness: Location
Correctness: Velocity
Comparing MCPs Using Summary Metrics
Degree of Networking and Quantity of Information Retrieved

- Degree of Networking
- Quality of Individual Information
- Degree of Shared Information
- Quality of Individual Sensemaking
- Quality of Individual Decisions
- Kill Ratio
  (Synchronization / Effectiveness)

Overall average over information quality dimensions and package members
Influence of Organic Info Quality and Degree of Info Sharing on Quality of Individual Information

Quality of Organic Information
- Objective Measures
  - Correctness
  - Consistency
  - Currency
  - Precision

- Fitness for Use
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness

Quality of Individual Information
- Objective Measures
  - Correctness
  - Consistency
  - Currency
  - Precision

- Fitness for Use
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness

Degree of Networking
- Network
  - Reach
  - Quality of Service
  - Network Assurance
  - Network Agility
- Net Ready Nodes
  - Capacity
  - Connectivity
  - P&R Capability Support
  - Node Assurance

Degree of Information
- “Share-ability”
  - Quantity of Posted Info
  - Quantity of Retrievable Info
  - Ease of Use

Quality of Organic Information:
- Degree of Networking
  - Quality of Organic Information
- Degree of Information
  - Quality of Individual Information

Objective Measures:
- Correctness
- Consistency
- Currency
- Precision

Fitness for Use:
- Completeness
- Accuracy
- Relevance
- Timeliness

Network
- Reach
- Quality of Service
- Network Assurance
- Network Agility

Net Ready Nodes
- Capacity
- Connectivity
- P&R Capability Support
- Node Assurance

Degree of Information
- “Share-ability”
  - Quantity of Posted Info
  - Quantity of Retrievable Info
  - Ease of Use

Quality of Individual Information
- Objective Measures
  - Correctness
  - Consistency
  - Currency
  - Precision

- Fitness for Use
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness

Rand 8/3/2004 Slide 93
Quality of Individual Information: Correctness

Quality of Organic Information

Objective Measures
- Correctness
- Consistency
- Currency
- Precision

Fitness for Use
- Completeness
- Accuracy
- Relevance
- Timeliness

Exogenous variables:
- Correctness of organic information
- Whether the info was retrieved in original form
- Whether the presentation of the info introduces errors

Voice Only Link 16

Degree of Information “Share-ability”

Objective Measures
- Correctness
- Consistency
- Currency
- Precision

Fitness for Use
- Completeness
- Accuracy
- Relevance
- Timeliness

Quantity of Posted Info
Quantity of Retrievable Info
Ease of Use
Quality of Individual Information: Voice Only vs. Link 16

Voice Only

Threat Tracks

Blue Tracks

Link 16 + Voice

Threat Tracks

Blue Tracks

AWACS

Blue 11 & 12

Blue 13 & 14

$Q_1$ Completeness: Detection

$Q_2$ Correctness: ID

$Q_3$ Correctness: Location

$Q_4$ Correctness: Velocity
Comparing MCPs Using Summary Metrics

Quality of Individual Information

- Degree of Information
  - "Share-ability"
- Degree of Networking
- Quality of Organic Info
- Kill Ratio (Synchronization / Effectiveness)
- Degree of Shared Information
- Quality of Individual Sensemaking
- Quality of Individual Decisions

Overall average over information quality dimensions and package members
Influence of Information “Share-ability” and Nature and Quality of Interactions on Degree of Shared Information

**Quality of Individual Information**
- Objective Measures
  - Correctness
  - Consistency
  - Currency
  - Precision
- Fitness for Use
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness

**Quality of Individual Sensemaking: Awareness**
- Objective Measures
  - Correctness
  - Consistency
  - Currency
  - Precision
- Fitness for Use
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness

**Quality of Interactions**
- Depth
  - Quantity
  - Quality
  - Reach
  - Selectivity
  - Intensity
  - Latency
  - Mode
  - Agility
  - Robustness
  - Flexible

**Quality of Interactions**
- Innovative
  - Adaptable
  - Individual Characteristics
  - Risk Prop
  - Competence
  - Trust
  - Org. Ident
  - Confidence

**Degree of Information “Share-ability”**
- Ease of Use
- Quantity of Posted Info
- Quantity of Retrievable Info

**Degree of Shared Information**
- Objective Measures
  - Extent
  - Quality
    - Completeness
    - Correctness
    - Accuracy
    - Relevance
    - Timeliness

**Degree of Shared Sensemaking: Shared Awareness**
- Objective Measures
  - Extent
  - Quality
    - Completeness
    - Correctness
    - Accuracy
    - Relevance
    - Timeliness

**Organizational Characteristics**
- Risk Prop
- Trust
- Size
- Diversity
- Autonomy
- Interdependence
- Org. & Ind. Behavior
- Cooperation
- Efficiency
- Synchronization
- Degree of Eng
- T vs. T
Computing Extent of Shared Information

Quality of Interactions
- Depth
  - Quantity
  - Quality
- Breadth
  - Reach
  - Selectivity
- Intensity
- Continuity
- Latency
- Synchronicity
- Mode
- Agility
- Robustness
- Flexible
- Response
- Innovative
- Adaptable

Individual Characteristics
- Risk Prop
- Competed
- Trust
- Confidence

Organizational Characteristics
- Risk Prop
- Competed
- Trust
- Confidence
- Size
- Hardness
- Diversity
- Permanence
- Autonomy
- Structure
- Interdepend

Organizational & Individual Behavior
- Cooperation
- Efficiency
- Syn

Deg. Of Eng
- T vs. T

Degree of Information “Share-ability”
- Quantity of Posted Info
- Quantity of Retrievable Info
- Ease of Use

Degree of Shared Information
Objective Measures
- Quality
  - Completeness
  - Accuracy
  - Relevance
  - Currency
  - Timeliness

Degree of Shared Sensemaking: Shared Awareness
Objective Measures
- Quality
  - Completeness
  - Accuracy
  - Timeliness
  - Uncertainty

Whether sender can communicate info with receiver
Whether sender and receiver are part of the same collaborative group
Number of communications “hops” between sender and receiver
Probability that sender will attempt to share information with receivers

f(...)
Degree of Shared Information: Extent of Shared Track Information

- **Voice Only**
- **Voice + Link 16**

All blue AC have the same shared information in this example (all listen to the same voice channel or receive the same Link 16 broadcasts)

- **Q^T_1** Completeness: Detection
- **Q^T_2** Correctness: ID
- **Q^T_3** Correctness: Location
- **Q^T_4** Correctness: Velocity
Comparing MCPs Using Summary Metrics
Degree of Shared Information

- Quality of Individual Information
  - Degree of Information
  - "Share-ability"
- Degree of Networking
- Quality of Organic Info
- Kill Ratio (Synchronization / Effectiveness)

Overall average over information quality dimensions and package members

* Voice
* Voice + Link 16
Influence of Information “Share-ability” and Nature and Quality of Interactions on Individual Awareness, Understanding, and Decisions: Timeliness

Quality of Individual Sensemaking: Awareness
- Objective Measures
  - Correctness
  - Consistency
  - Currency
  - Precision
- Fitness for Use
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness
  - Uncertainty

Quality of Individual Sensemaking: Understanding
- Objective Measures
  - Correctness
  - Consistency
  - Currency
  - Precision
- Fitness for Use
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness
  - Uncertainty

Quality of Individual Decisions
- Objective Measures
  - Consistency
  - Currency
  - Precision
  - Mode of D. M.
  - Agility
  - Robustness
  - Flexibility
  - Responsiveness
  - Innovativeness
  - Risk Propensity
  - Adaptability
  - Appropriateness
  - Competence
  - Confidence
  - Hardness
  - Permanence
  - Structure
  - Synergy
  - Efficiency
  - Structure
  - Risk Propensity
  - Adaptability

Quality of Interactions
- Depth
  - Quantity
  - Quality
  - Distance
  - Selectivity
  - Intensity
  - Robustness
  - Flexible
  - Innovative
  - Adaptive
  - Response
  - Individual Characteristics
    - Risk Prop
    - Competence
    - Trust
    - Organic Identity
    - Confidence
  - Organizational Characteristics
    - Risk Prop
    - Competence
    - Trust
    - Size
    - Diversity
    - Autonomy
    - Interdependence
    - Organizational & Individual Behavior
    - Cooperation
    - Efficiency
    - Synthesis
    - Degree of Engagement
    - T vs. T

Degree of Information “Share-ability”
- Objective Measures
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness
  - Uncertainty

Degree of Shared Sensemaking: Shared Awareness
- Objective Measures
  - Extent
  - Quality
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness
  - Uncertainty

Degree of Shared Sensemaking: Shared Understanding
- Objective Measures
  - Extent
  - Quality
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness
  - Uncertainty

Quality of Collaborative Decisions
- Objective Measures
  - Extent
  - Appropriateness
  - Robustness
  - Flexibility
  - Responsiveness
  - Innovativeness
  - Degree of Engagement
  - Adaptability
  - Uncertainty
Quality of Individual Sensemaking and Decision Making: Timeliness

- **Quality of Individual Sensemaking: Awareness**
  - Objective Measures
    - Correctness
    - Consistency
    - Currency
    - Precision
  - Fitness for Use
    - Completeness
    - Accuracy
    - Relevance
    - Timeliness
    - Uncertainty

- **Quality of Individual Sensemaking: Understanding**
  - Objective Measures
    - Correctness
    - Consistency
    - Currency
    - Precision
  - Fitness for Use
    - Completeness
    - Accuracy
    - Relevance
    - Timeliness
    - Uncertainty

- **Quality of Individual Decisions**
  - Objective Measures
    - Consistency
    - Currency
    - Precision
    - Mode of D. M.
  - Fitness for Use
    - Appropriateness
    - Completeness
    - Accuracy
    - Relevance
    - Timeliness
    - Uncertainty
    - Risk Propensity
    - Risk Propensity
  - Agility
    - Robustness
    - Flexibility
    - Responsiveness
    - Innovativeness
    - Adaptability

- **Quality of Interactions**
  - Objective Measures
    - Accuracy
    - Completeness
    - Relevance
    - Timeliness
    - Uncertainty
  - Fitness for Use
    - Quality
    - Selectivity
    - Mode
    - Response
    - Adaptability
    - Confidence
    - Competence
    - Trust
    - Structure
    - Autonomy

- **Degree of Information “Share-ability”**
  - Quantity of Posted Info
  - Quantity of Retrievable Info
  - Ease of Use

- **Exogenous variables:**
  - Training, experience, etc.
  - Whether the focus of interactions is on information gathering and validation or sensemaking/decision making
  - The number of participants
  - Whether the intensity of the interactions matches the requirements of the mission
  - Whether the command structure allows for flexible roles and distributed decision making
Comparing MCPs Using Summary Metrics

Quality of Individual Sensemaking and Decisions (Notional)

- Quality of Individual Information
- Degree of Information
  - “Share-ability”
- Degree of Networking
- Quality of Organic Info
- Kill Ratio
  - (Synchronization / Effectiveness)

Overall average over information quality dimensions and package members
Influence of Individual and Collaborative Decisions on Synchronization and Effectiveness / Agility

Quality of Individual Decisions
- Objective Measures
  - Consistency
  - Currency
  - Precision
- Mode of D. M.
- Fitness for Use
  - Appropriateness
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness
  - Uncertainty

Quality of Collaborative Decisions
- Objective Measures
  - Extent
  - Consistency
  - Currency
  - Precision
  - Mode of D. M.
- Fitness for Use
  - Appropriateness
  - Completeness
  - Accuracy
  - Relevance
  - Timeliness
  - Uncertainty
- Agility
  - Robustness
  - Flexibility
  - Responsiveness
  - Innovativeness
  - Adaptability

Degree of Decision/ Plan Synchronization
- Synchronized Decisions/Plans

Degree of Actions/ Entities Synchronized
- Synchronized Actions
- Synchronized Entities

Operating Environments

Degree of Effectiveness/ Agility
- Achievement of Objectives
- Agility
- Timeliness
- Efficiency
Major Products

NCW Conceptual Framework

Air-to-Air Case Study

Quality of Information

Quality of有机信息

Kill Ratio

(Synchronization / Effectiveness)

Degree of Information “Share-ability”

Degree of Networking

Degree of Actions/ Entities Synchronized

Degree of Information

Degree of Shared Information

Degree of Shared Sensemaking

Shared Awareness

Shared Understanding

Degree of Networking

Degree of Effectiveness/ Agility

Quality of Collaborative Decisions

Quality of Individual Information

Quality of Individual Sensemaking

Awareness

Understanding

Quality of Individual Decisions

Quality of Organic Information

Quality of Organic Info

Quality of Organizational Information

Value Added Services

Degree of Decision/ Plan Synchronization

Degree of Decision

Quality of Individual Decisions

Quality of Individual Sensemaking

Shared Sensemaking

Operating Environments

Degree of Networking

Degree of Actions/ Entities Synchronized

Degree of Information

Degree of Information

Degree of Shared Information

Degree of Shared Sensemaking

Shared Awareness

Shared Understanding

Degree of Networking

Degree of Effectiveness/ Agility

Quality of Collaborative Decisions

Quality of Information

Quality of Organic Information

Value Added Services
Accomplishments

“Getting NCW Theory and Metrics Right…”
– Extension and refinement of framework
  • Sensemaking
  • Social domain
  • Quantitative metrics
  • Operational application

“…And Applied Enterprise-Wide”
– Initial application of framework
  • Ongoing partnerships with allies (UK, Australia, Canada)
  • Joint Force C2 concept (JCS)
  • DPG Study 9: Alternative Interoperability Strategies (JCS/J8 led)
  • Multinational LOE (JFCOM/J7, J9 led)
  • Transformation of GCCS (DISA)
## Degree of Networking: Net Ready Nodes

Nodes that are capable of sharing information and collaborating with others

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>Ability of the node to exchange and use data (incorporates data exchange rate, CPU, memory, disk storage, etc.)</td>
</tr>
<tr>
<td>Connectivity</td>
<td>Number and types of access modes supported</td>
</tr>
<tr>
<td>Posting and Retrieving Capability Support</td>
<td>Degree to which node has the ability to post and retrieve information in desired formats and places</td>
</tr>
<tr>
<td>Collaboration Support</td>
<td>Number and types of collaboration applications supported</td>
</tr>
<tr>
<td>Node Assurance</td>
<td>Extent to which node supports services that facilitate the assurance of information in the areas of privacy, availability, integrity, authenticity, and nonrepudiation</td>
</tr>
</tbody>
</table>
# Degree of Networking:
## Net Ready Nodes

Nodes that are capable of sharing information and collaborating with others

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<thead>
<tr>
<th>Attribute</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>Largest bandwidth the node can access (56K bps, 1.5Mbps, etc.)</td>
</tr>
<tr>
<td>Connectivity</td>
<td>Vector of number and types of access modes supported</td>
</tr>
<tr>
<td>Posting and Retrieving Capability Support</td>
<td>Percentage of nodes that can post and retrieve in desired formats</td>
</tr>
<tr>
<td>Collaboration Support</td>
<td>Number and types of collaboration applications supported</td>
</tr>
<tr>
<td>Node Assurance</td>
<td>Categorical rating from “highly secure” to “not secure”</td>
</tr>
<tr>
<td></td>
<td>(estimated from assessment of node’s installed security software, hardware, and usage policies)</td>
</tr>
</tbody>
</table>