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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)



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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



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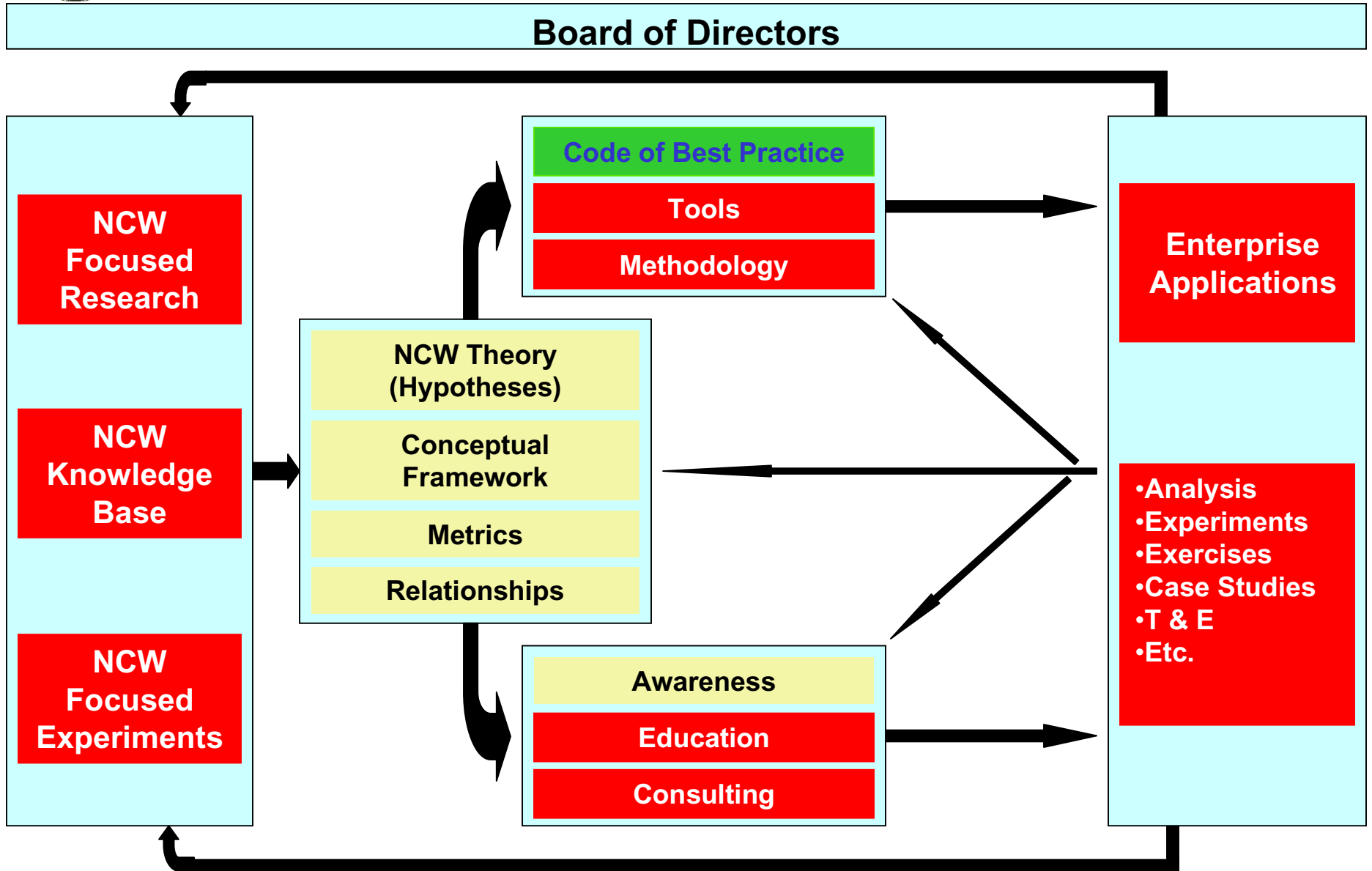
DoD Priorities and Goals

- 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





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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

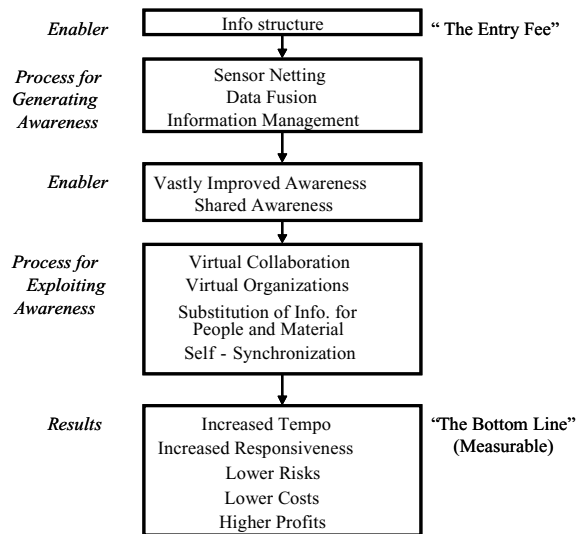
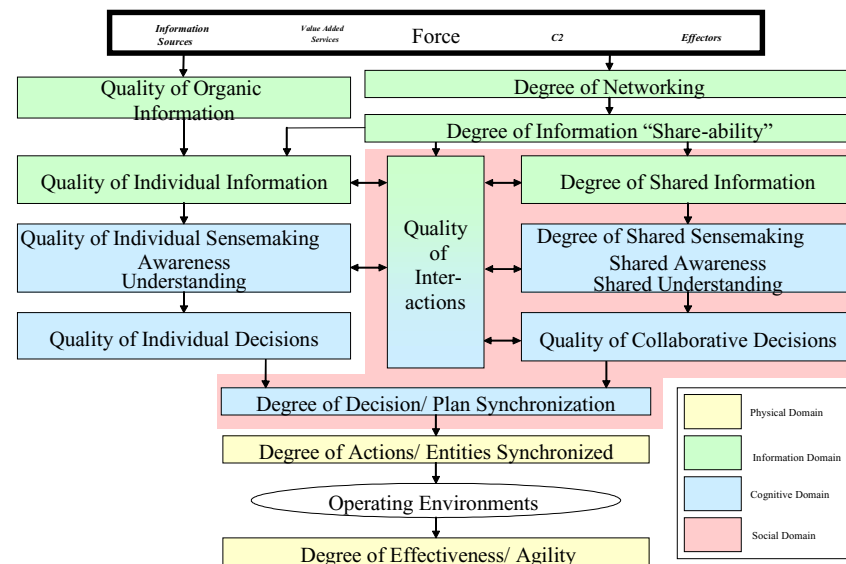
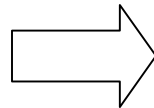


Figure 6. The Network Centric Enterprise

NCW Foundation (1999)

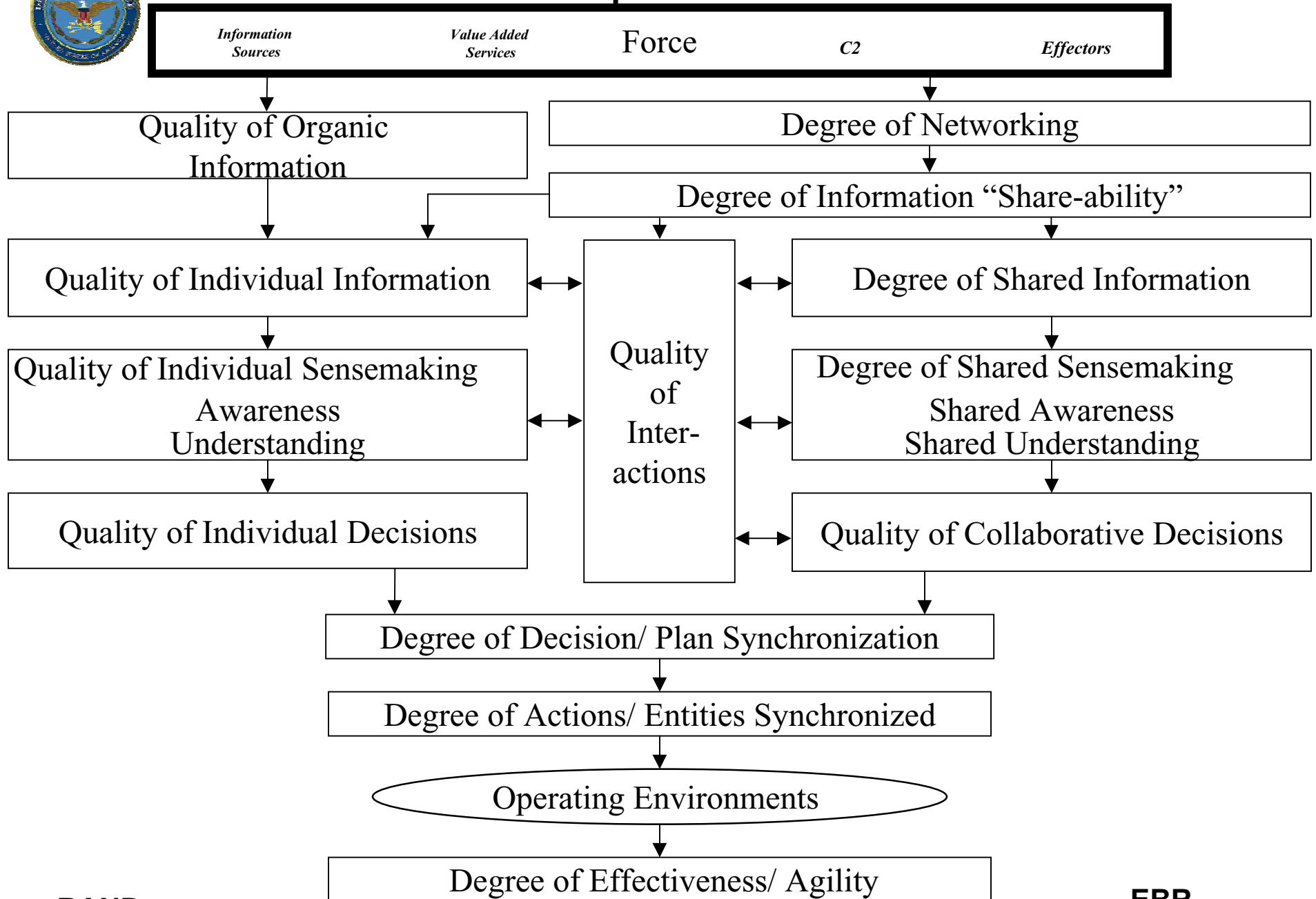
P 36, Network Centric Warfare: Developing and Leveraging Information Superiority. CCRP. 1999



NCW Conceptual Framework (2002)



NCW Conceptual Framework





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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

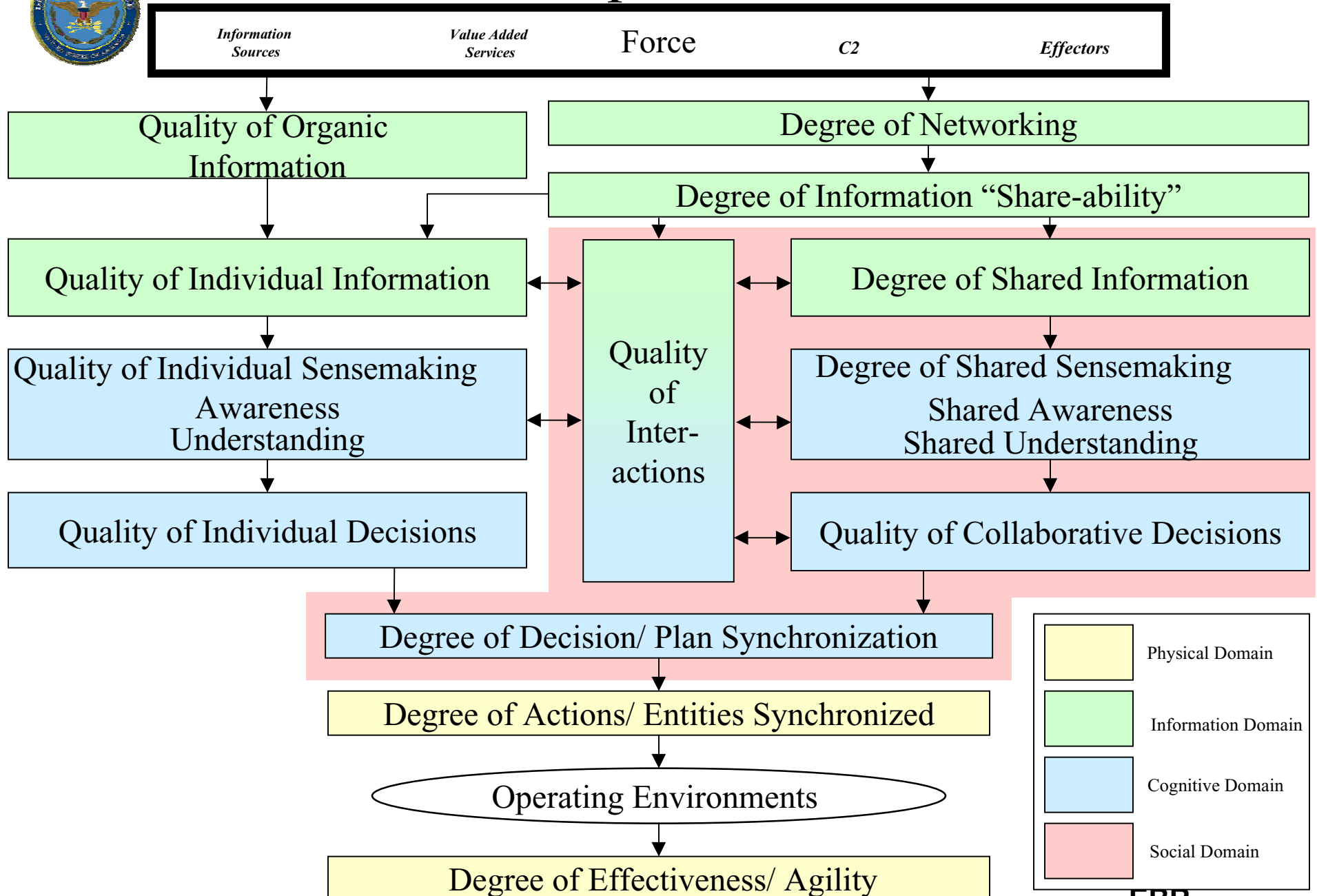
Social Domain

where force entities interact



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NCW Conceptual Framework

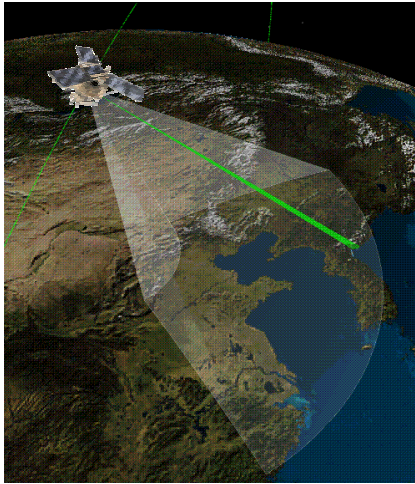




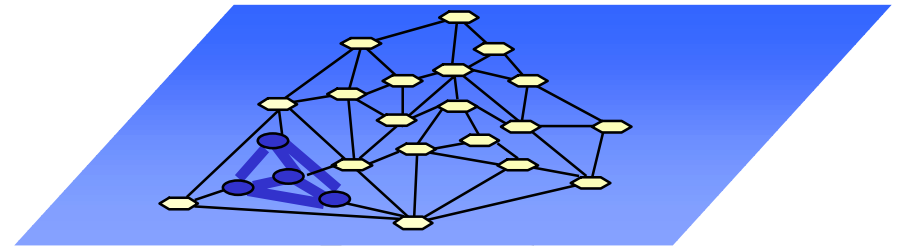
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Force

Key Elements: Nodes and Networks



Sensors



Networks

Command & Control



People

Effectors (Shooters)



EBR

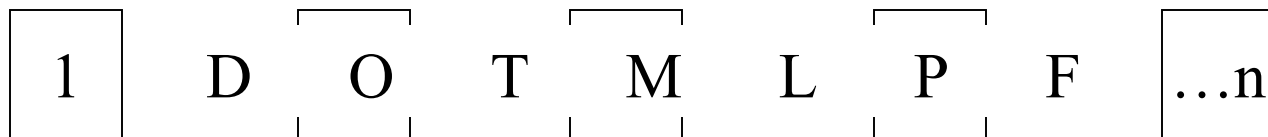


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Force

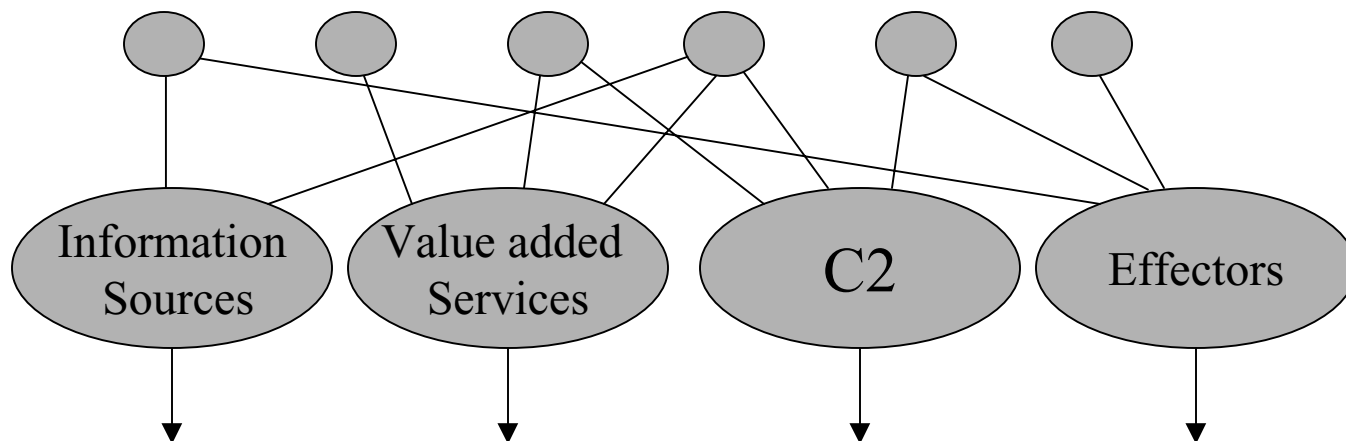
Measures for Key Elements

Mission
Capability
Packages



Elements
(Network,
Nodes)

People, Platforms, Facilities, Units, Networks, ...



Roles/
Functions

Measures
(Exogenous
to the NCW
framework)

- | | | | |
|--|--|---|--|
| <ul style="list-style-type: none"> • Phenomenology • Coverage • Persistence • Performance • Agility | <ul style="list-style-type: none"> • Service • Capability • Capacity • Quality of Service • Agility | <div style="border: 1px solid black; padding: 10px; margin: 0 auto; width: 80%;"> Embedded in
the NCW
conceptual
framework </div> | <ul style="list-style-type: none"> • Effects • Coverage • Persistence • Survivability • Agility |
|--|--|---|--|



NCW Conceptual Framework: Summary of Attributes (1)

Force

Information Sources

Value Added Services

C2

Effectors

Quality of Organic 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

Quality of Individual Information

Objective Measures

Correctness

Consistency

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Precision

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Timeliness

Quality
of
Interactions

Degree of Information "Share-ability"

Quantity of Posted Info

Quantity of Retrievable Info

Ease of Use



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Degree of Networking: Network

The extent to which force entities are interconnected

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



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Degree of Networking: Network

The extent to which force entities are interconnected

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

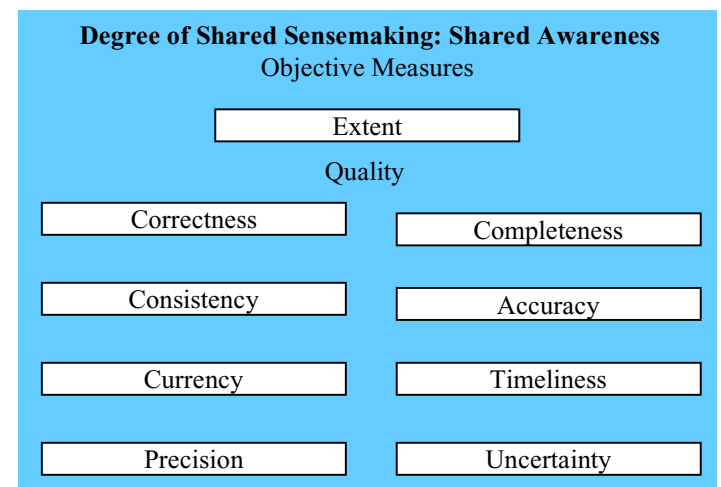
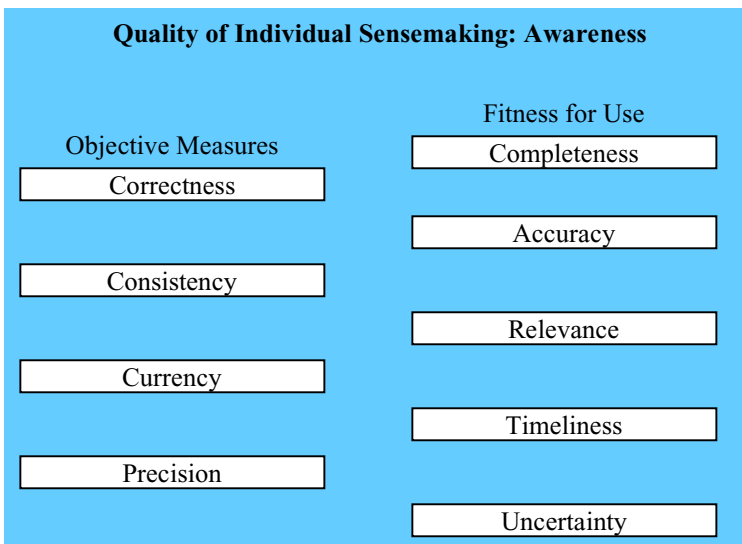
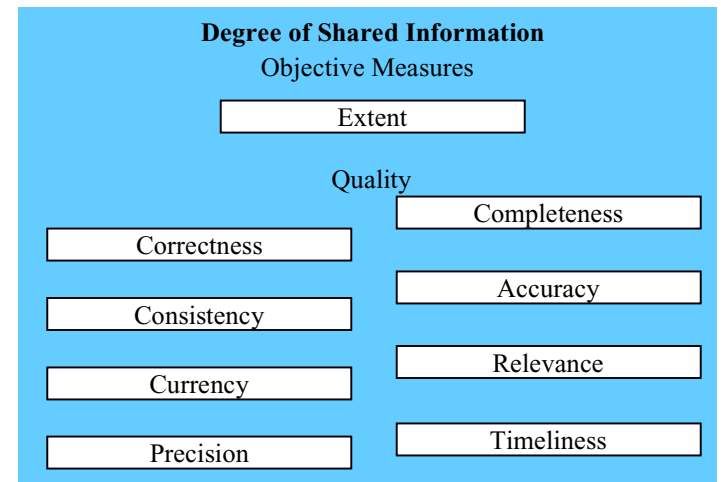
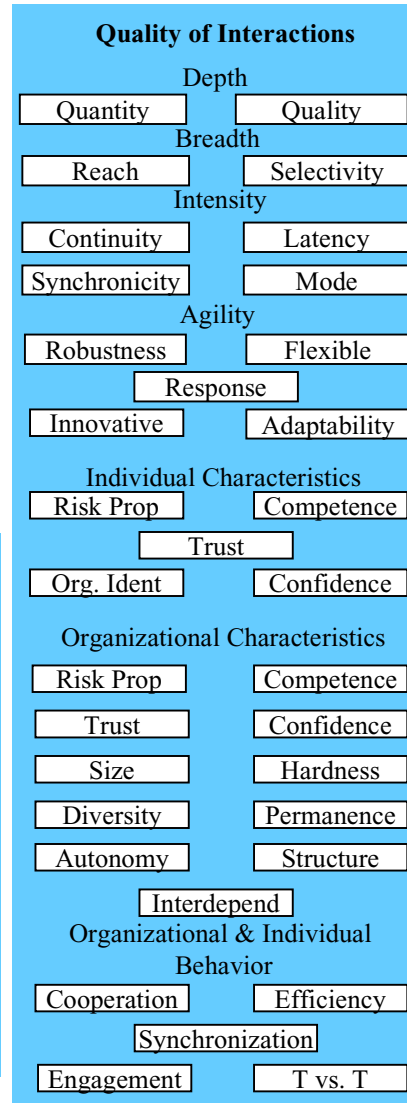
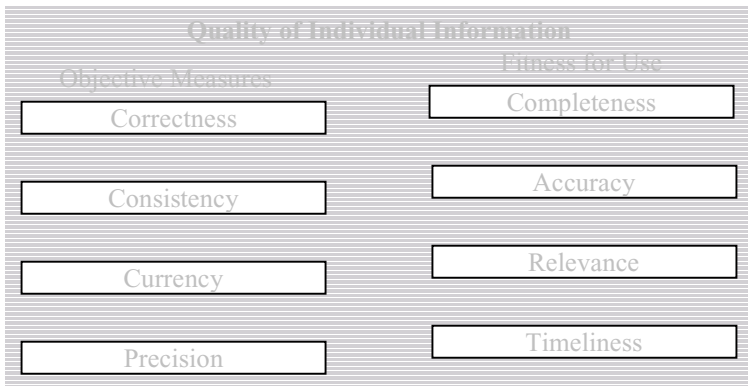


Degree of Networking: Network Agility

Attribute	Metrics
Robustness	<p>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.)</p> <p>Effectiveness of network across varying levels of attack/degradation (baseline level determined by SME, simulation, analysis, empirical analysis, etc.)</p> <p>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.)</p>
Responsiveness	<p>The timeliness of the response to an environmental change (baseline level determined by SME, simulation, analysis, empirical analysis, etc.)</p>
Flexibility	<p>Number of options for responding to an environmental change</p> <p>Compatibility of different responses (0=not compatible, 1=fully compatible; determined by SME, simulation, analysis, empirical analysis, etc.)</p>
Innovativeness	<p>Number of novel responses developed and implemented (baseline determined by SME, simulation, analysis, empirical analysis, etc.)</p>
Adaptiveness	<p>Number and timeliness of changes to network structure and processes (baseline determined by SME, simulation, analysis, empirical analysis, etc.)</p>



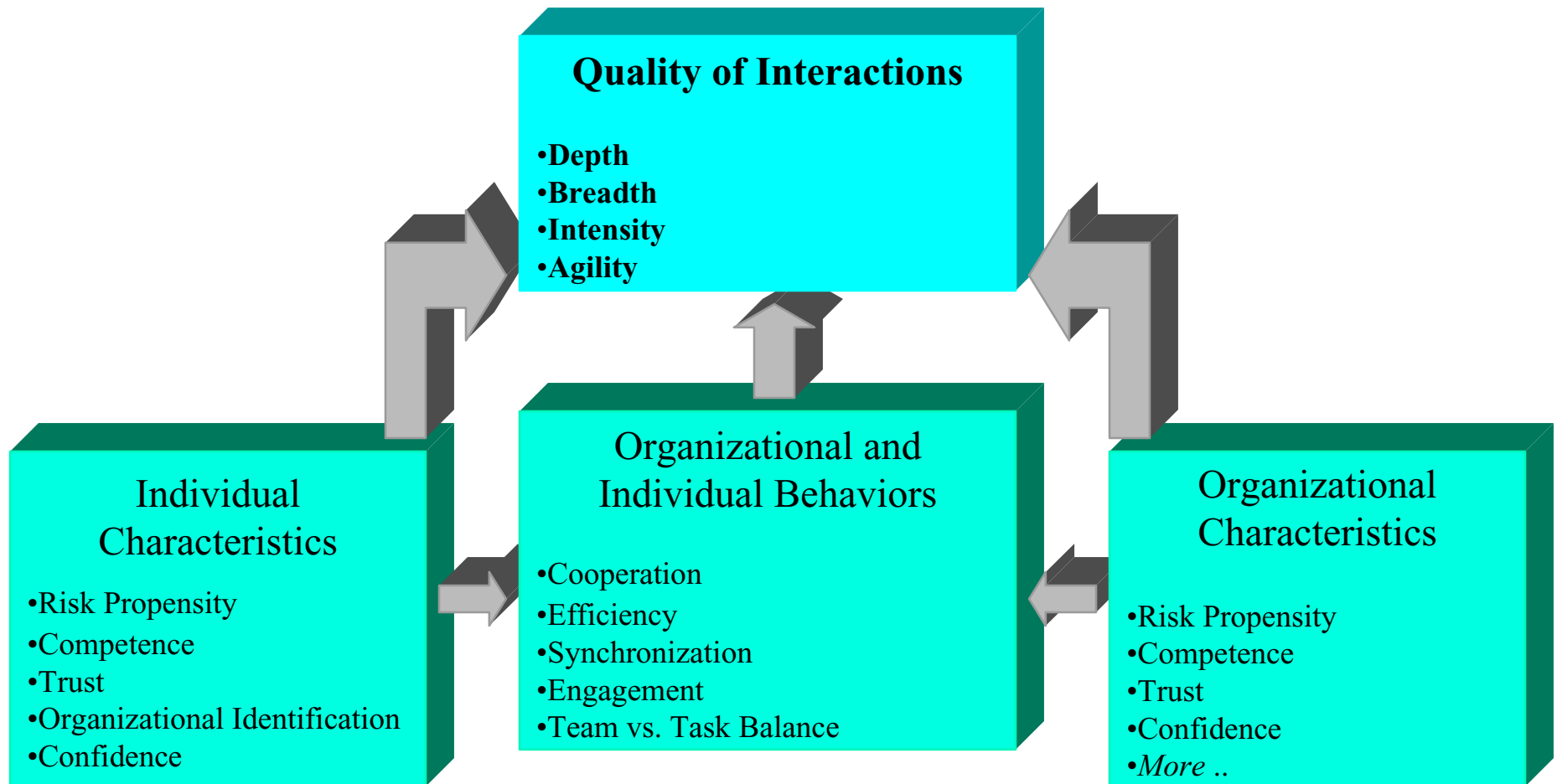
NCW Conceptual Framework: Summary of Attributes (2)





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

Top Level Attributes

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



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

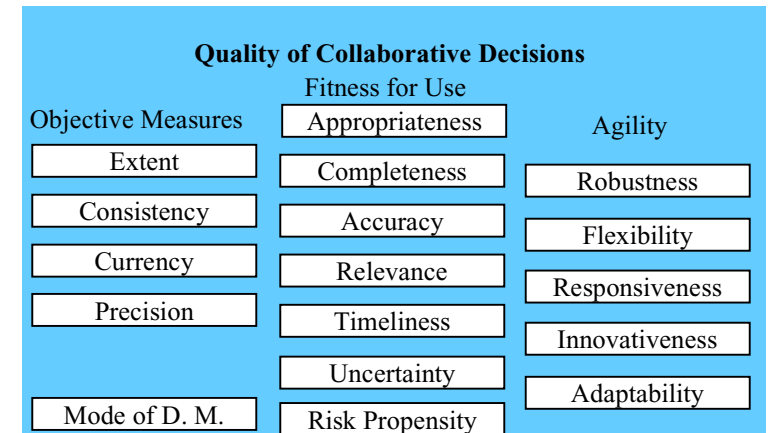
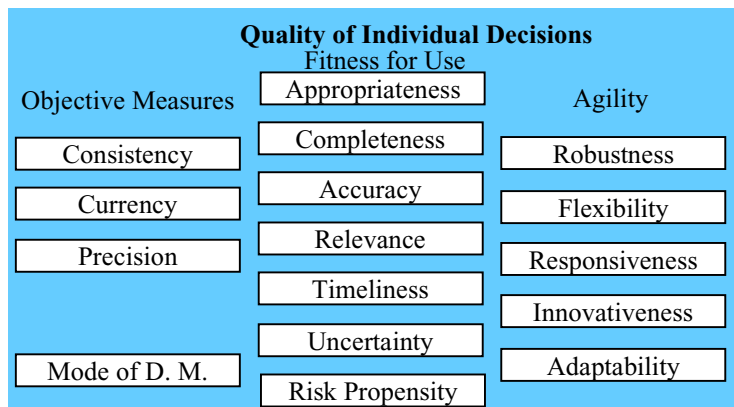
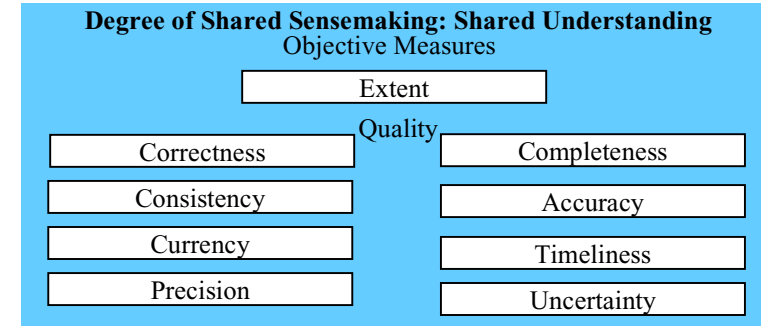
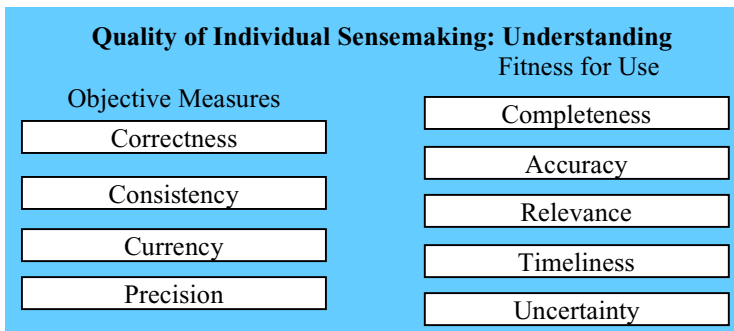
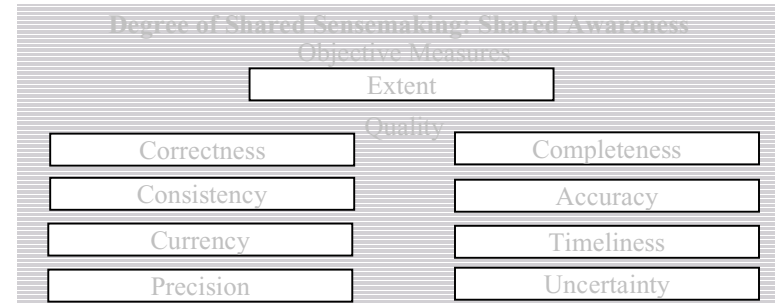
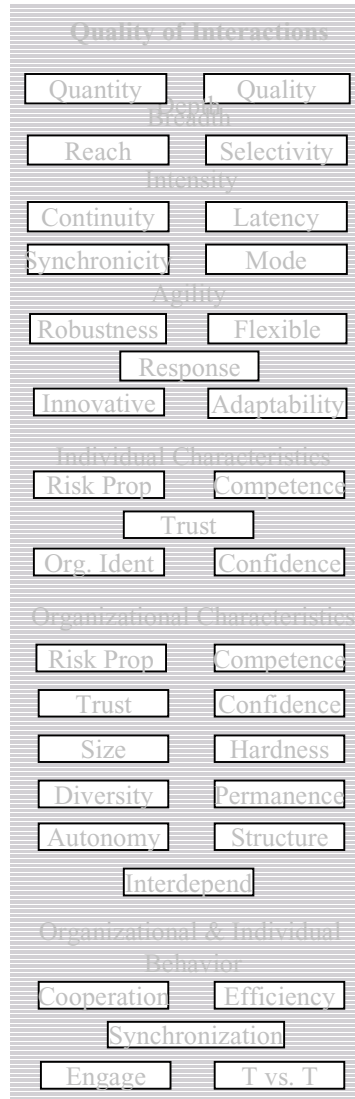
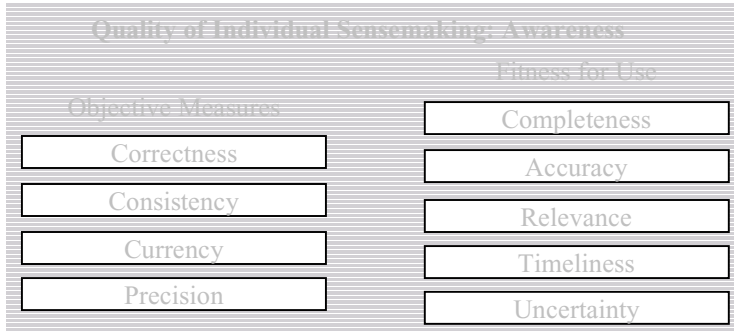


Degree of Shared Sensemaking: Shared Awareness

Attribute	Definition
Objective Measures	Measures quality in reference to criteria that are independent of the situation
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)





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Quality of Collaborative Decisions I

Attribute	Definition
Objective Measures	Measures quality in reference to criteria that are independent of the situation
Extent	Proportion of force entities that reach a collaborative decision
Consistency	Extent to which decisions are in agreement across force entities, within and across CoI
Currency	Time lag of decisions
Precision	Level of granularity of decisions
Fitness for Use Measures	Measures quality in reference to criteria that are determined by the situation
Appropriateness	Extent to which decisions are consistent with existing shared understanding, command intent and shared team values
Completeness	Extent to which relevant decisions encompass the necessary: <ul style="list-style-type: none"> •Depth: range of actions and contingencies included •Breadth: range of force elements included •Time: range of time horizons included
Accuracy	Appropriateness of precision of decisions for a particular use
Relevance	Proportion decisions that are important to the accomplishment of the task at hand
Timeliness	Extent to which currency of decision making is suitable to its use
Uncertainty	Inter-subjective assessment of confidence in decisions
Risk Propensity	Extent of risk aversion
Mode of Decision Making	Type of collaborative decision making structure utilized (authoritative decision making, consensus building, majority rule, etc.)



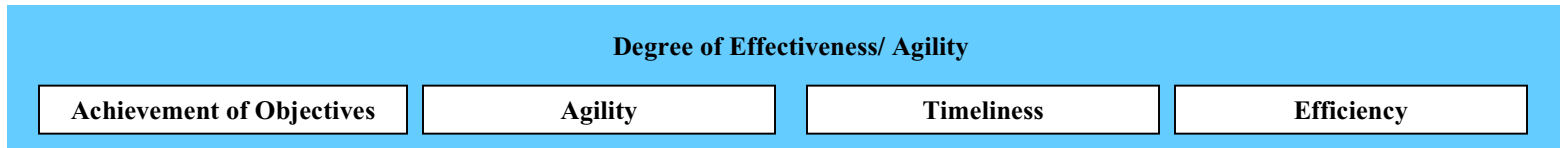
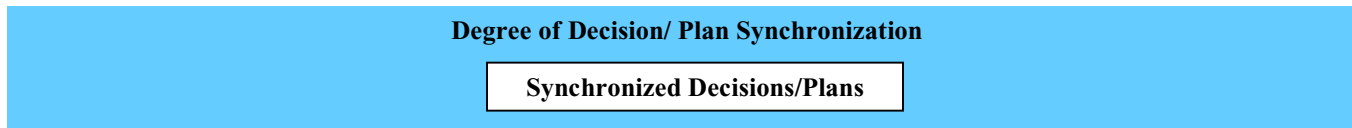
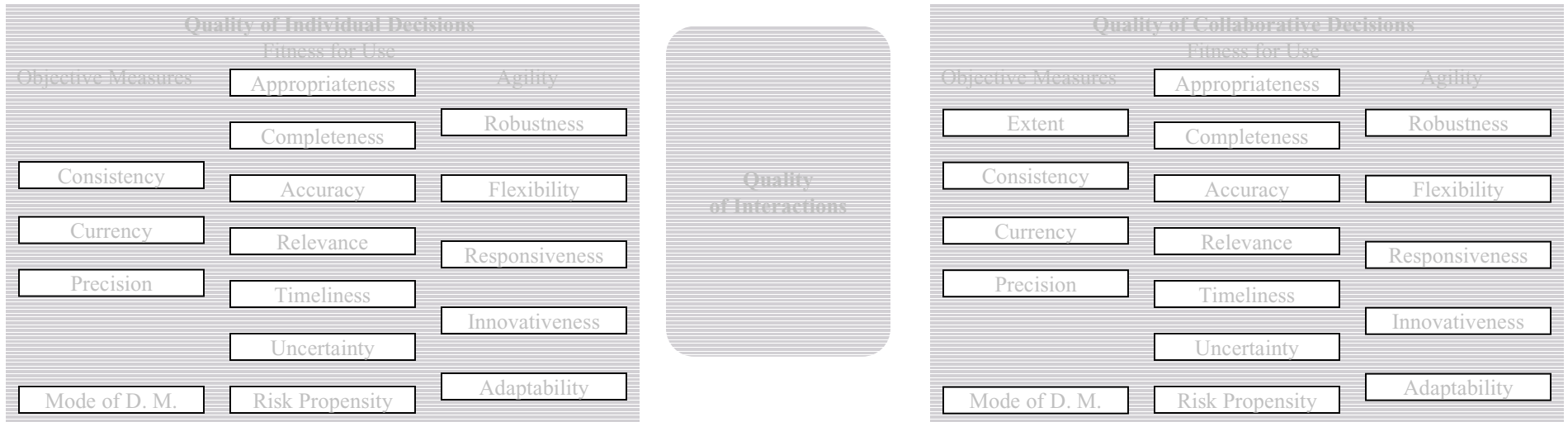
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Quality of Collaborative Decisions II

Attribute	Definition
Agility	
Robustness	Degree to which collaborative decision is dominant across a range of situations and degradation conditions
Flexibility	Degree to which collaborative decision allows force entities to maintain flexibility (i.e., incorporates multiple ways of succeeding)
Responsiveness	Degree to which collaborative decision is relevant and timely
Innovativeness	Degree to which collaborative decision reflects novel ways to perform known tasks and/or develops new ways of doing novel tasks
Adaptability	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



NCW Conceptual Framework: Summary of Attributes (4)





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



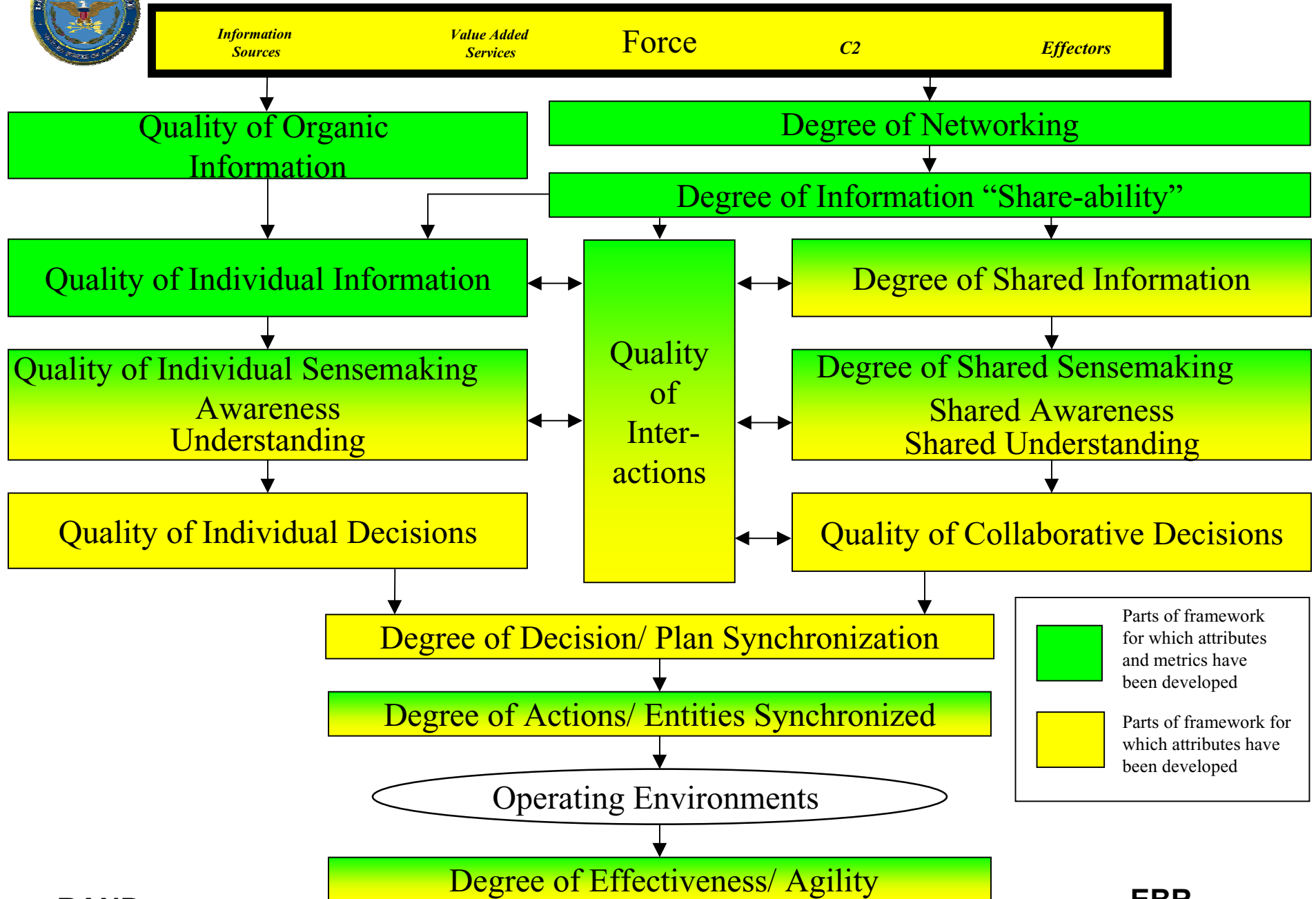
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Degree of Effectiveness / Agility

Attribute	Definition
Achievement of Objectives	Degree to which Military/Strategic/ Political/ Social/ Economic/ Diplomatic objectives were achieved
Agility	The degree to which force entities were robust, flexible, responsive, innovative, and adaptable
Time	Time required to achieve objective
Efficiency	Total cost of achieving objective



Framework: Attributes and Metrics





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?



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Agenda

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- 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



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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)

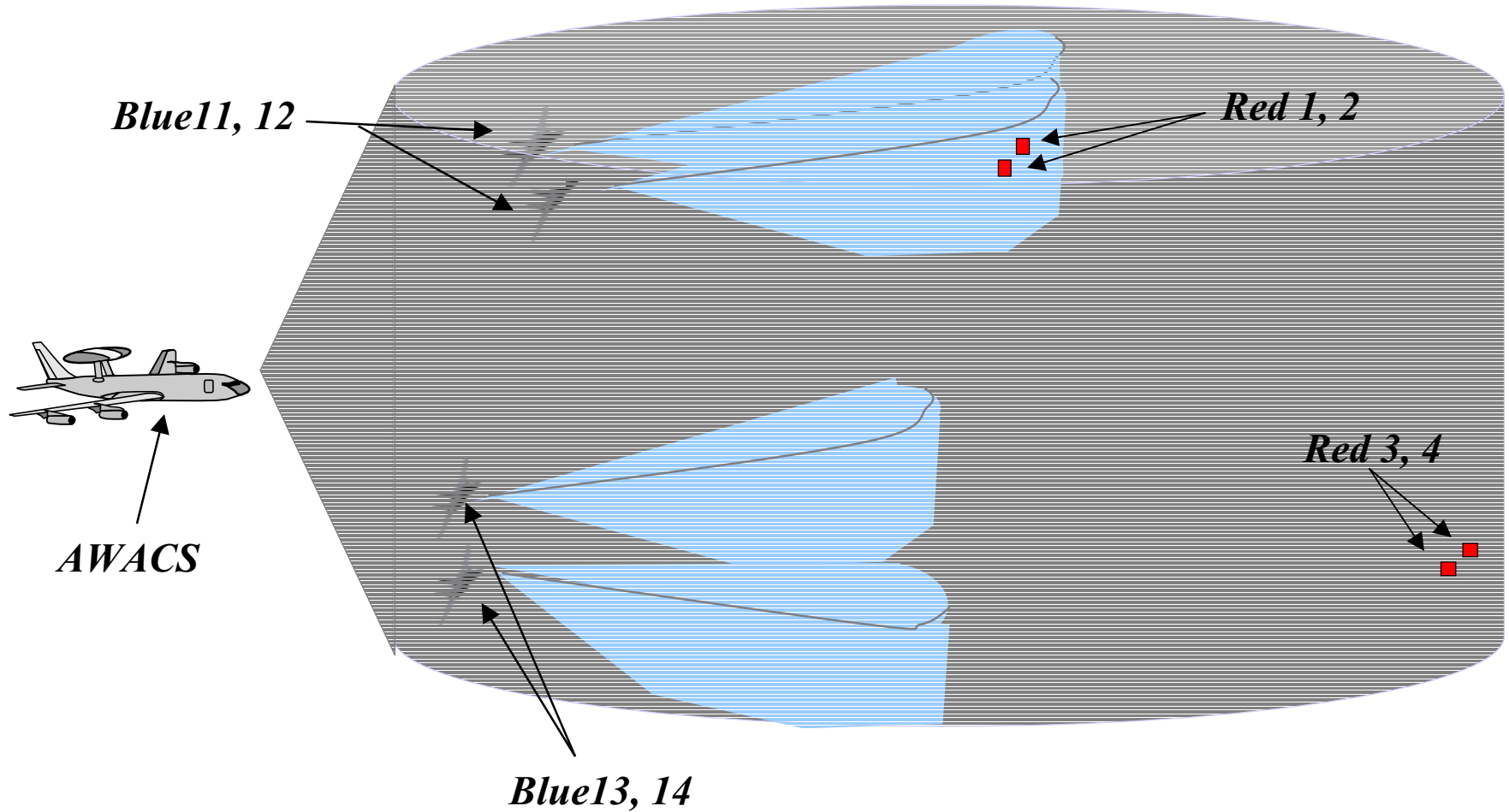
	Voice Only	Voice + Link 16
Day	3.10	8.11
Night	3.62	9.40



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Air-to-Air Scenario Exemplar

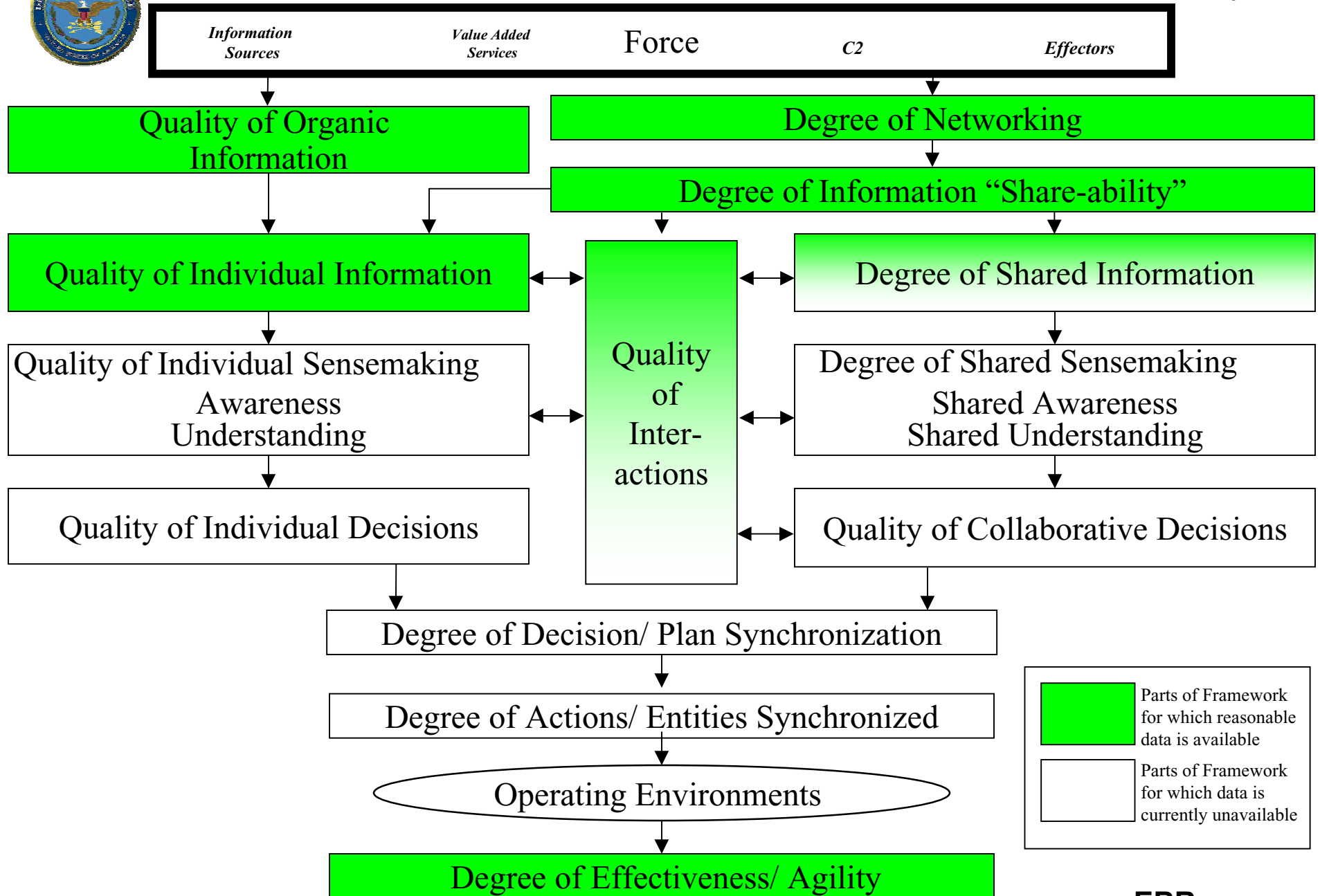
Four-on-Four Engagement





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Framework: Data Available for Case Study





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Force

**Mission
Capability
Packages**

**Voice Only
(MCP #1)**

**Voice + Link 16
(MCP #2)**

**Elements
(Network,
Nodes)**

AWACS

Voice Network

Data + Network

Air Craft

Roles

Information Sources

Value added Services

C2

Effectors

Functions

- Detect/
ID targets

- Fuse data
- ID info
- Distribute Info.

- Assign aircraft to targets
- Coordinate engagements

- Kill Targets

**Relevant
Attributes**

- Coverage
- Persistence
- Performance

- Capability
- Capacity
- Quality of Service

Embedded in
the NCW
conceptual
framework

- Target Destruction

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Influence of the Force on Quality of Organic Information

Force

Information Sources

Value Added Services

C2

Effectors



Quality of Organic 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

Quality of Individual Information

Objective Measures

Correctness

Consistency

Currency

Precision

Fitness for Use

Completeness

Accuracy

Relevance

Timeliness

Quality
of
Interactions

Degree of Information "Share-ability"

Quantity of Posted Info

Quantity of Retrievable Info

Ease of Use

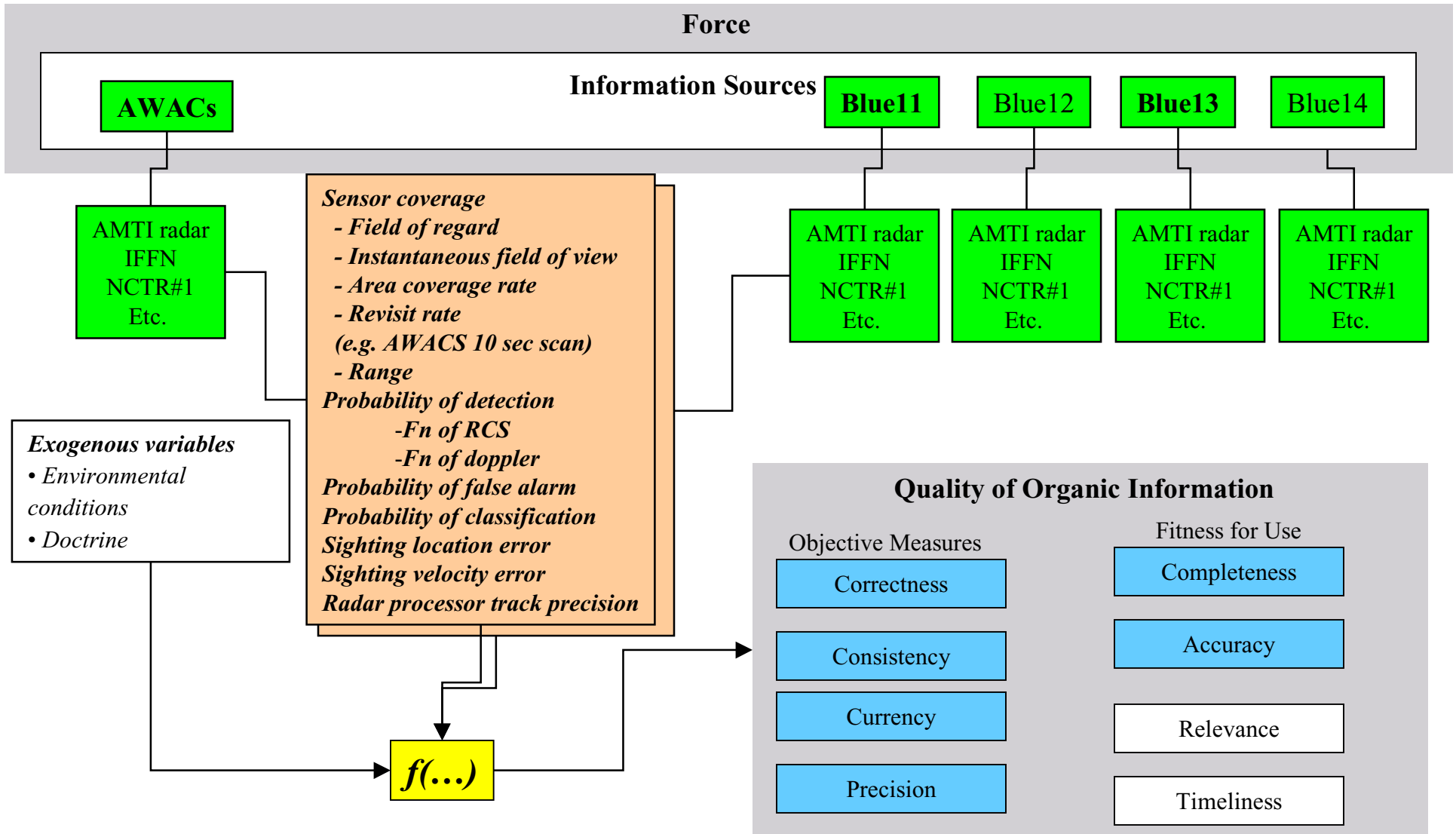
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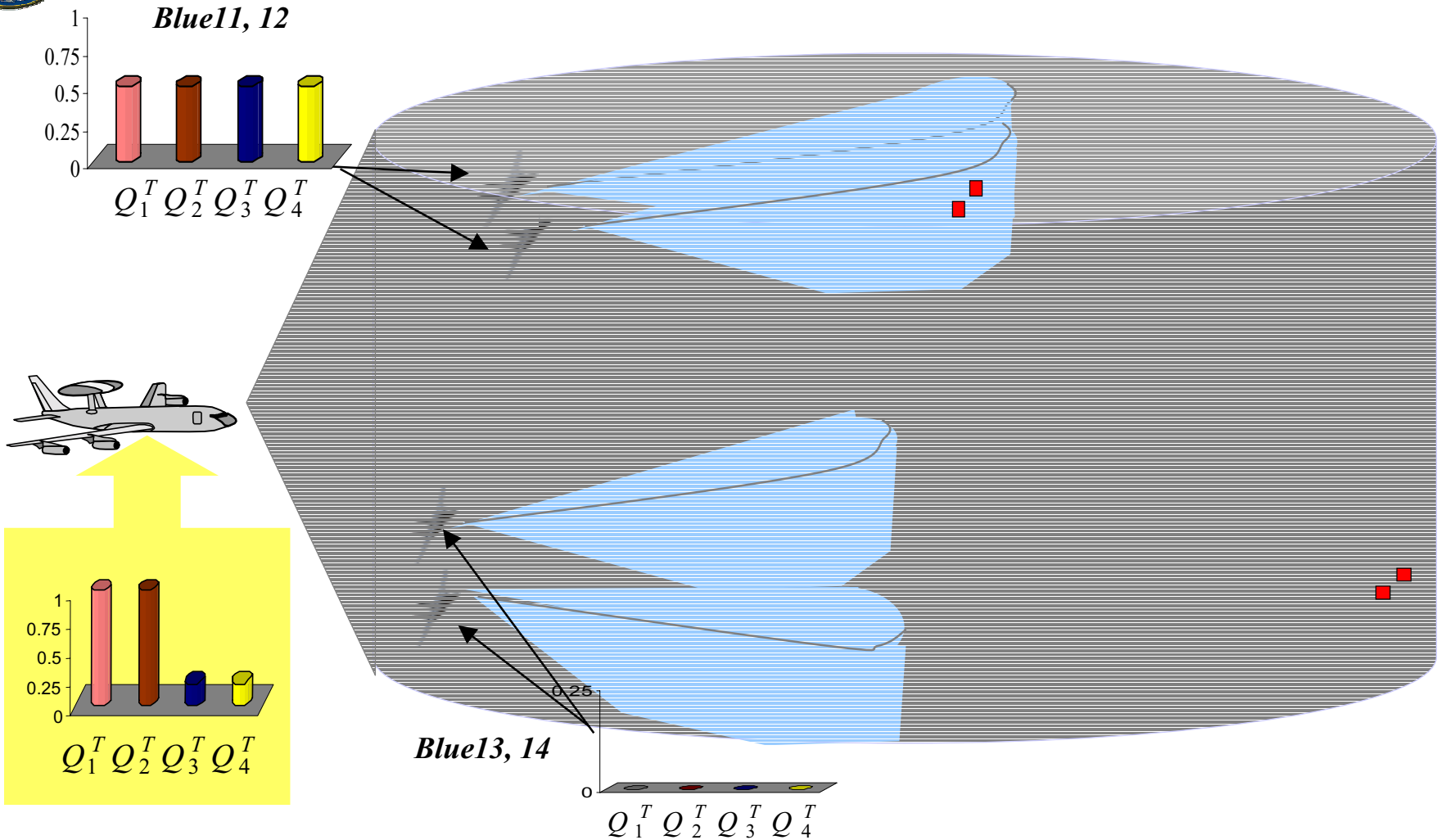
Computing Quality of Organic Information





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Quality of Organic Information: Threat Tracks



Q_1^T **Completeness: Detection**

Q_2^T **Correctness: ID**

Q_3^T **Correctness: Location**

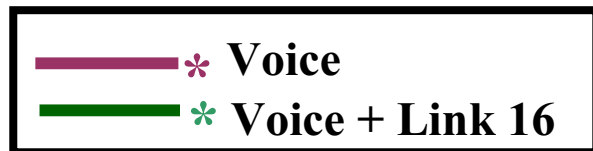
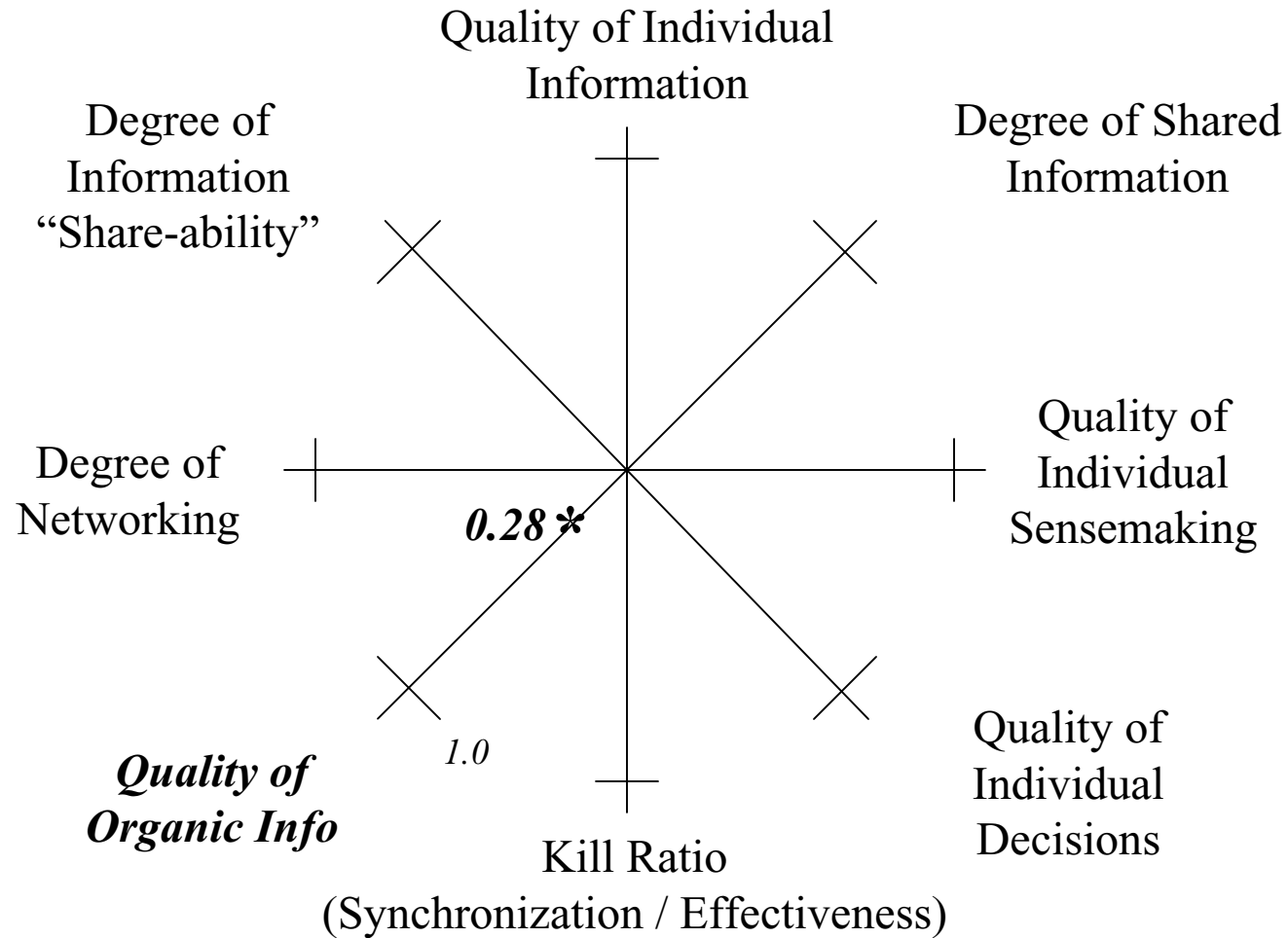
Q_4^T **Correctness: Velocity**



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Comparing MCPs Using Summary Metrics

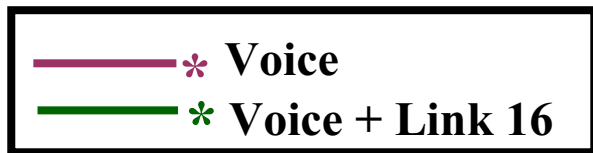
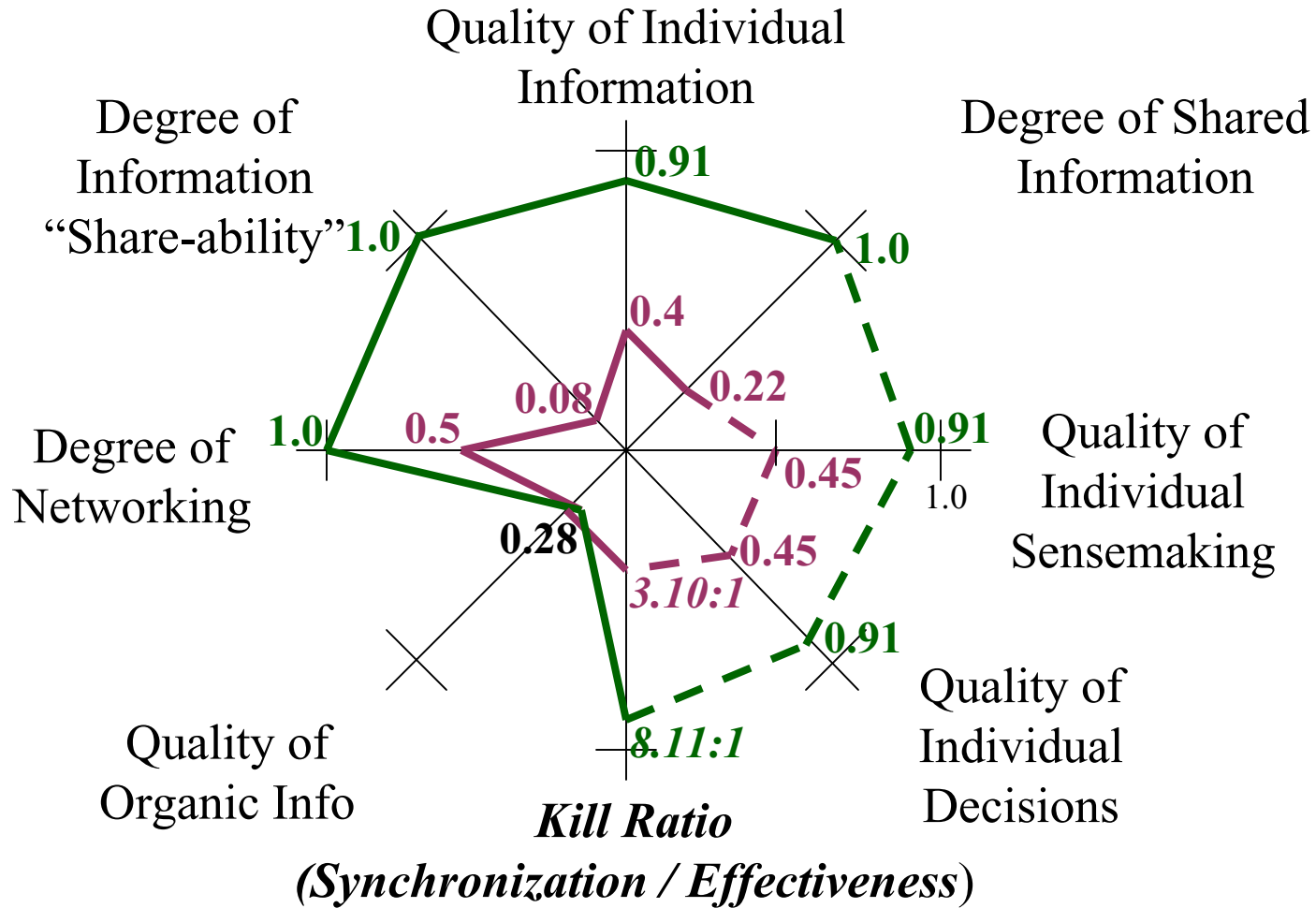
Quality of Organic Information



Overall average over information quality dimensions and package members



Comparing MCPs Using Summary Metrics Synchronization and Effectiveness



Overall average over information quality dimensions and package members

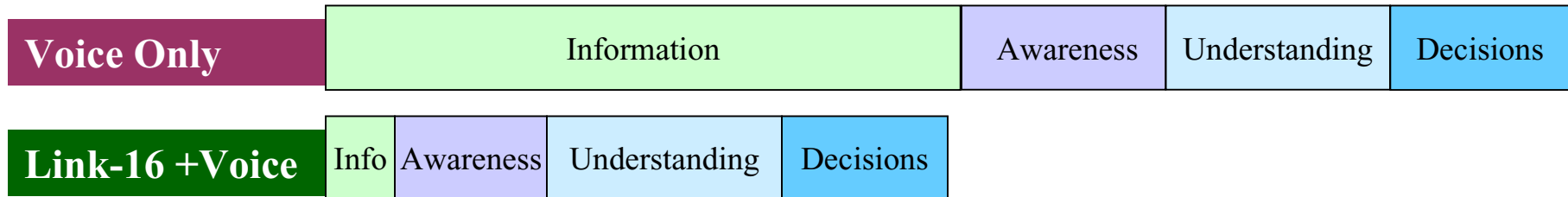


Quality of Sensemaking & Decisions Relative Speed and Competitive Advantage

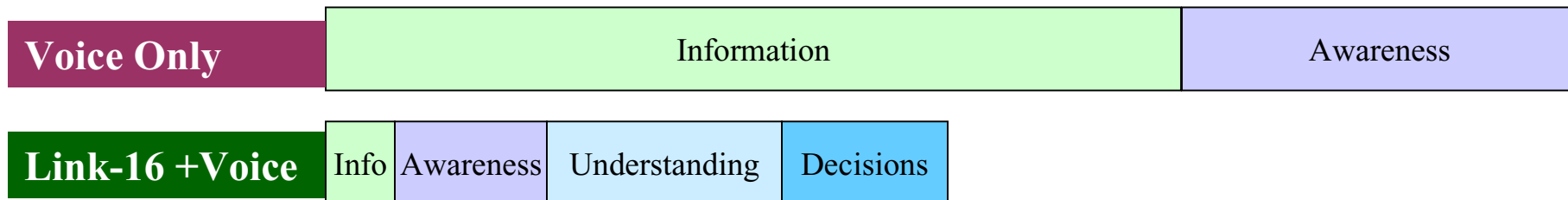
Hypotheses:

- *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)



B12 (Wingman)





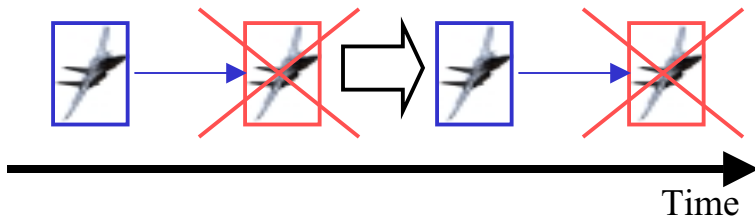
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Degree of Synchronization and Effectiveness

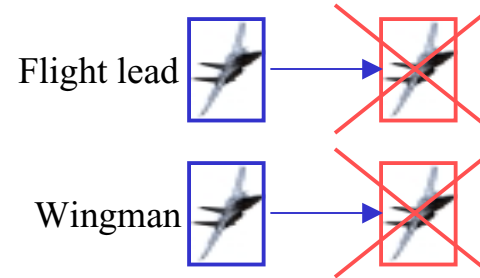
Reported Tactical Improvements Enabled by Voice + Link 16

- *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*

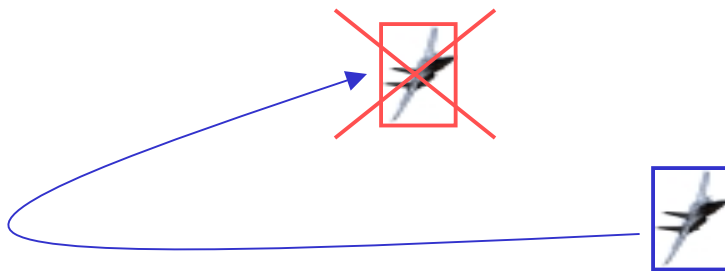
1. Increased numbers of engagements in the same time period



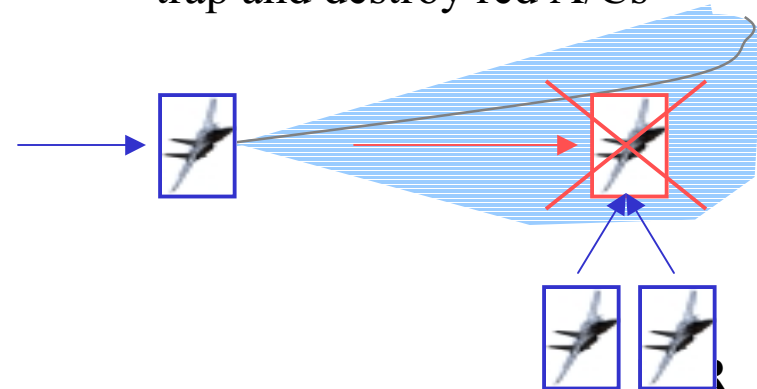
2. Employment of the wingman as combatant rather than defensive patroller



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



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





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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



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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

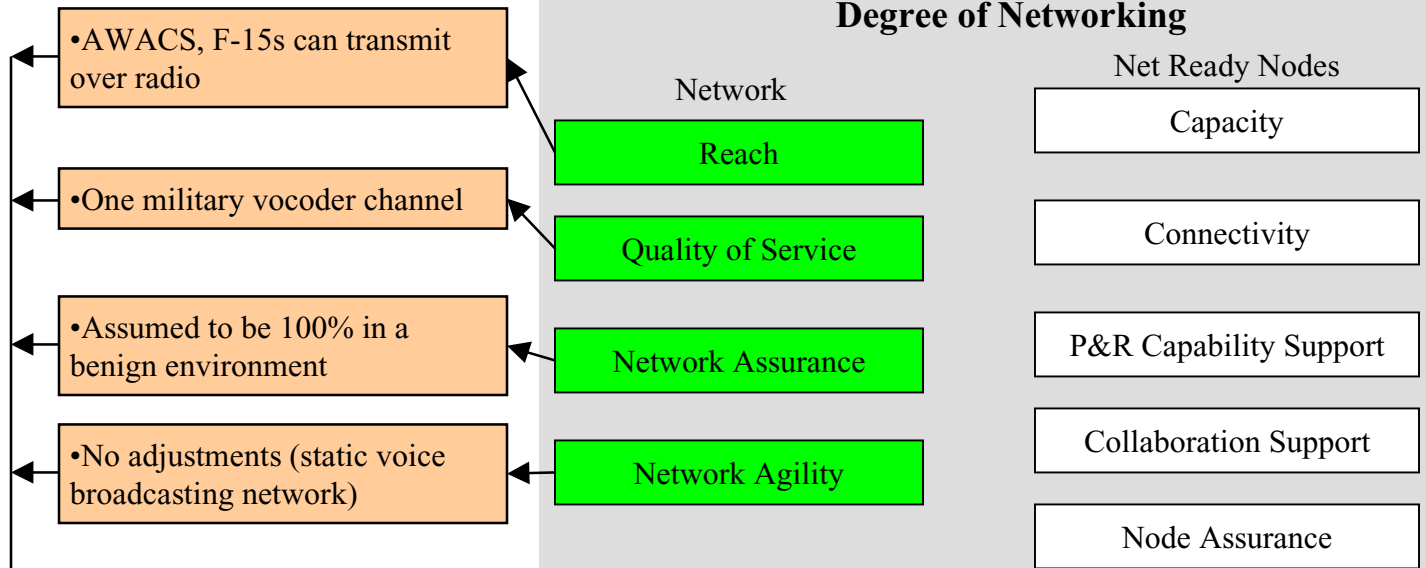


Computing Quantity of Posted Info: Track Info over Voice Only

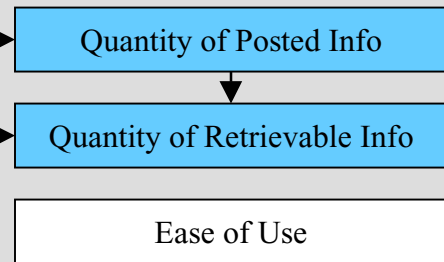
Force



Degree of Networking



Degree of Information "Share-ability"



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

$f(...)$

• In this scenario, quantity of posted info equals quantity of retrievable info, *except* for probability of hearing voice

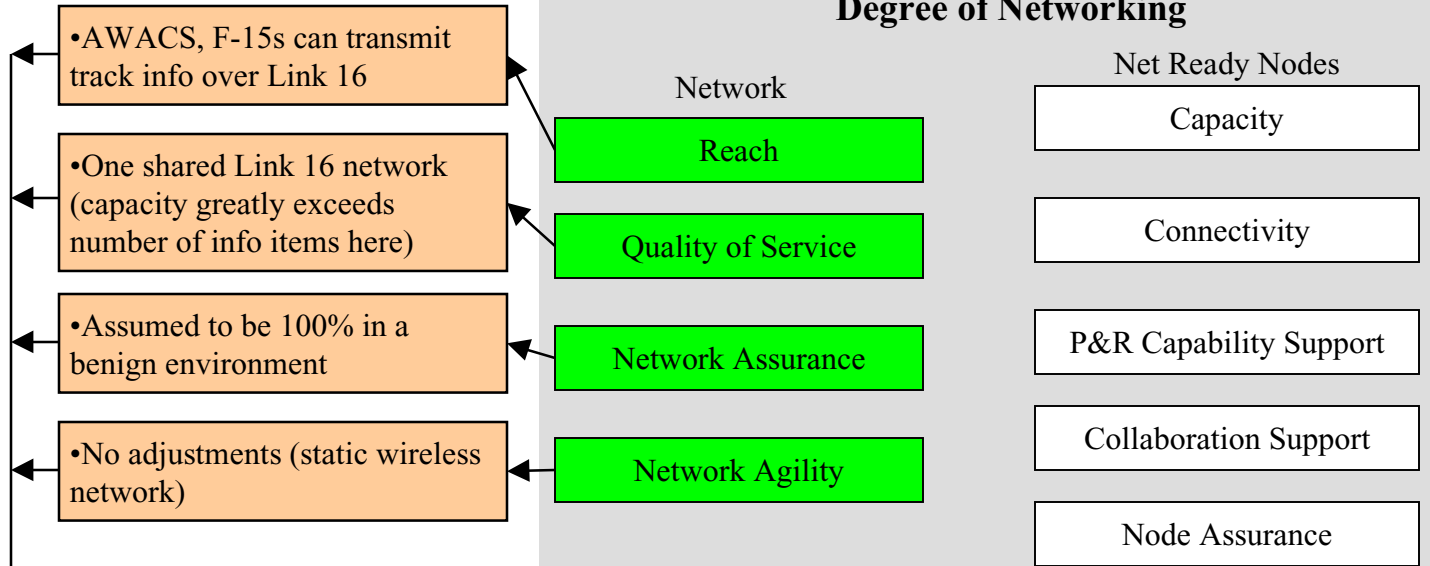


Computing Quantity of Posted Info: Track Info over Link 16

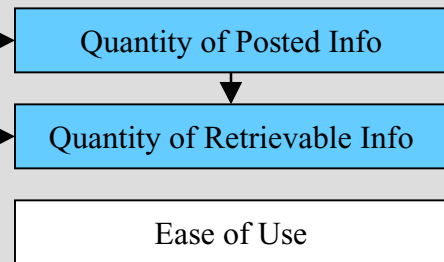
Force



Degree of Networking

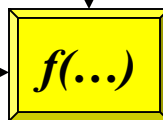


Degree of Information "Share-ability"



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

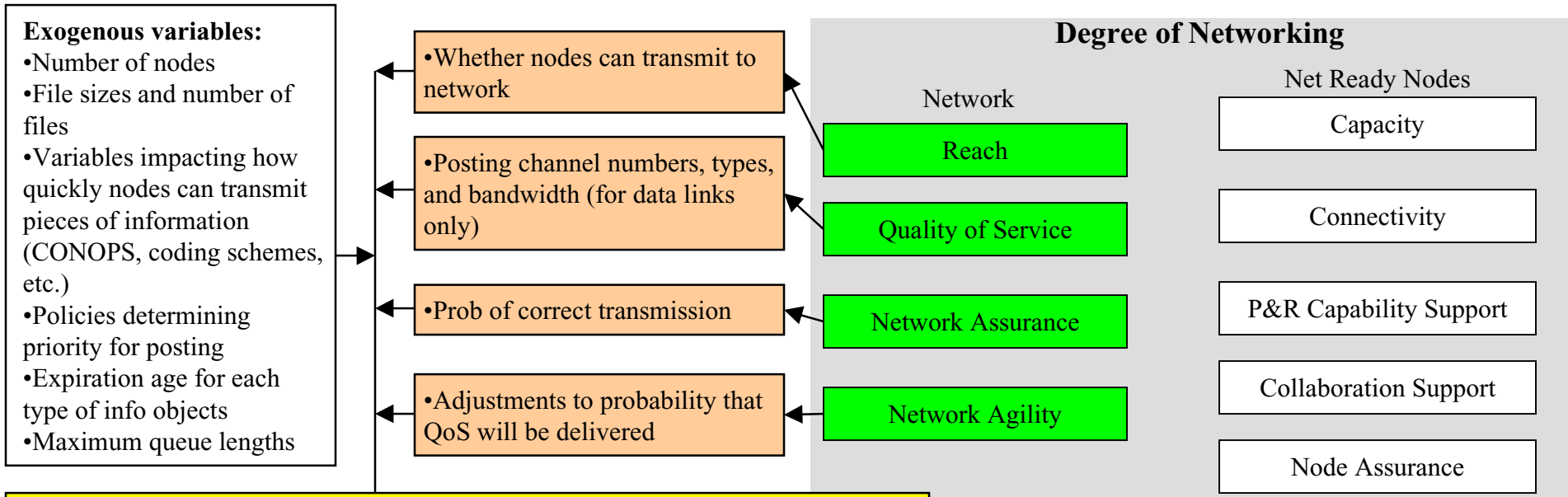


• In this scenario, quantity of posted info over Link 16 equals quantity of retrievable info



Computing Quantity of Posted Info: Detailed Function for Posted Info

Force



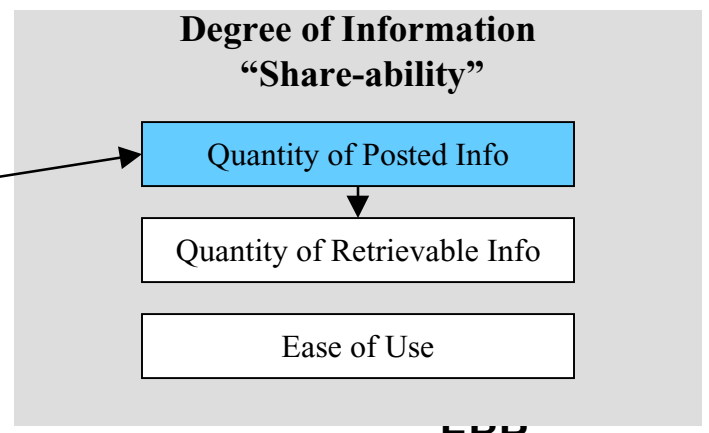
f(...): Vector for number of info objects that can be posted, by object type

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.

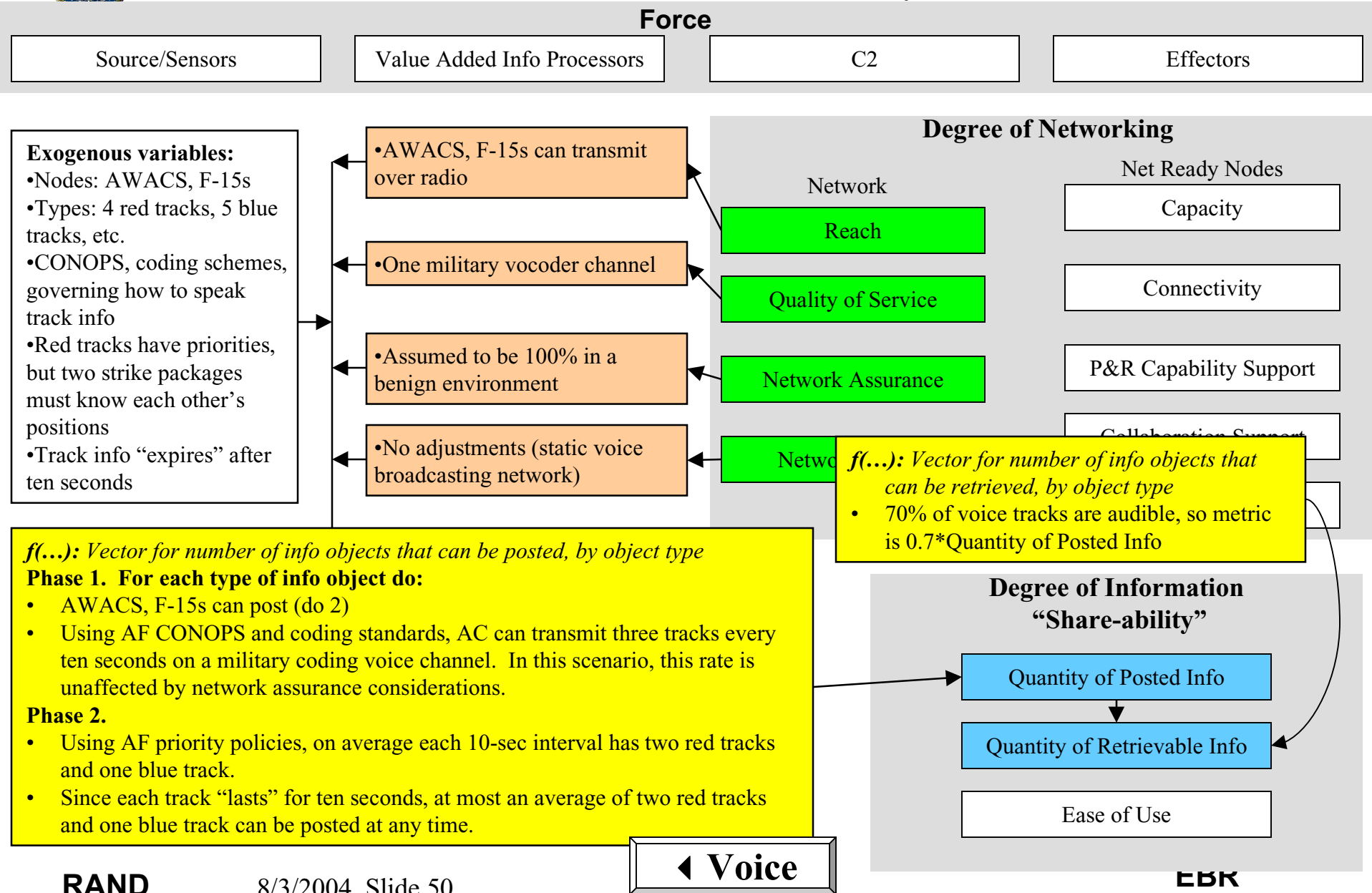
- Use *theoretical rates* for each info type plus priority policies to determine what *fractions of postings* will be of each info type.
- Multiply *fractions of postings* times *theoretical rates* times *expiration age* to get Num(type) for each info type.



◀ General



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



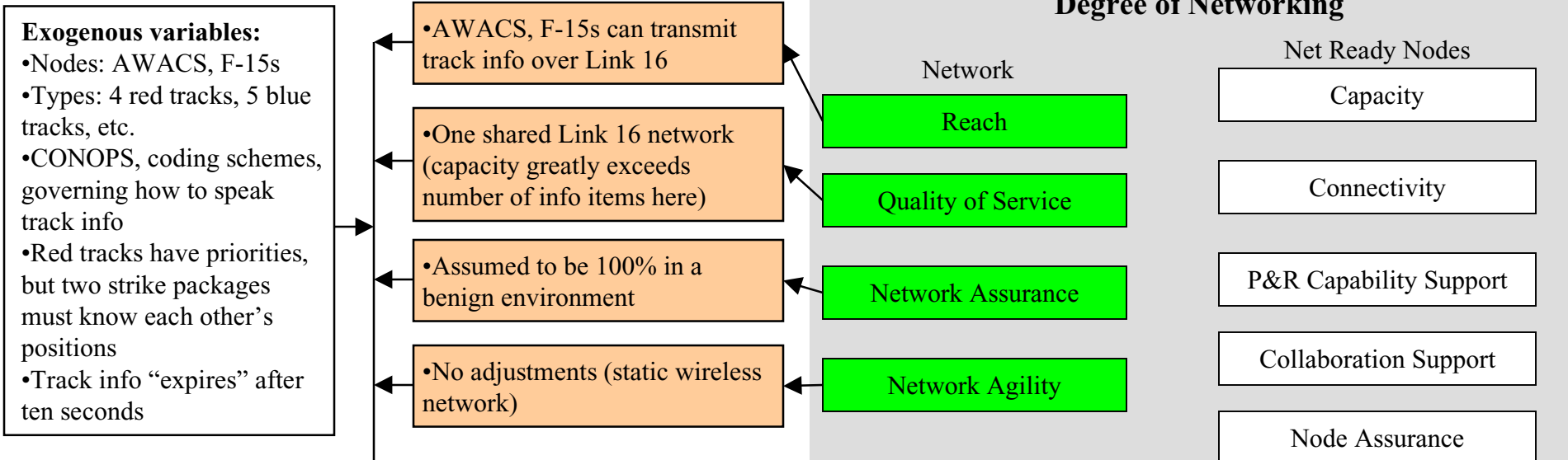


Computing Quantity of Posted Info: Detailed Function for Link 16 Network

Force



Degree of Networking



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

Phase 1. For each type of info object, do:

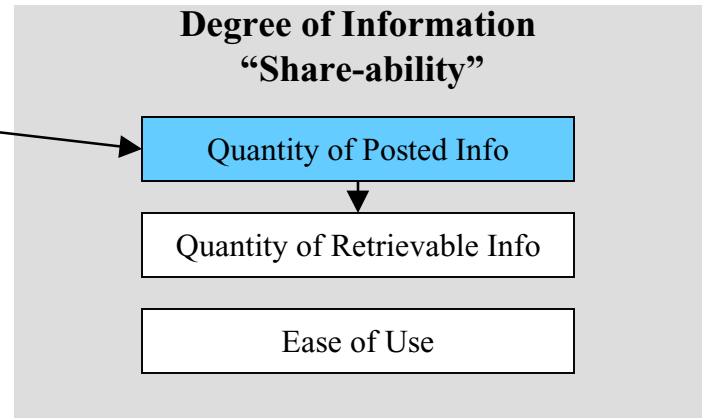
- AWACS, F-15s can post (do 2)
- Using Link 16 capacity and AF track coding standards, rate exceeds maximum number of tracks updated every second.

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.

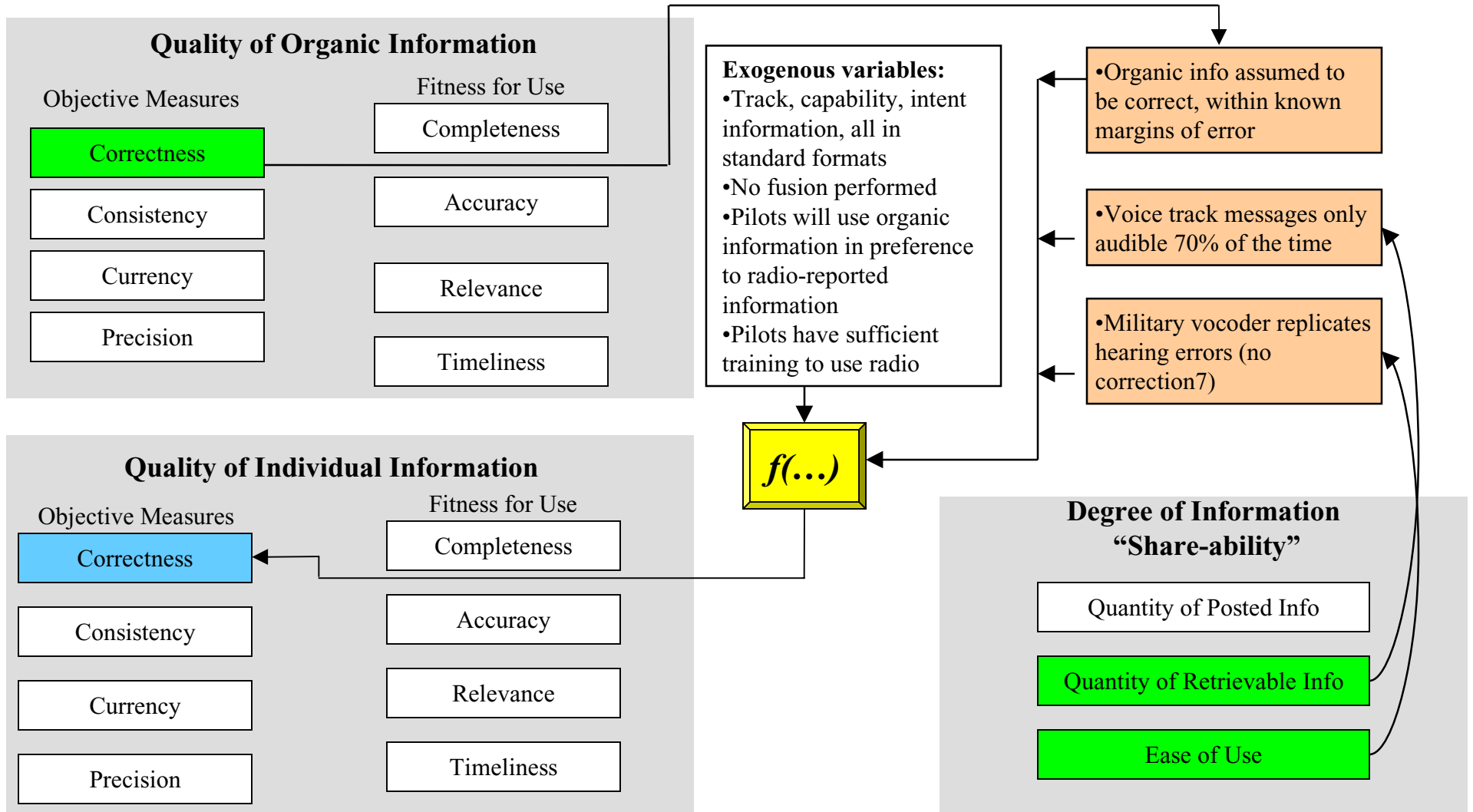
Degree of Information

"Share-ability"



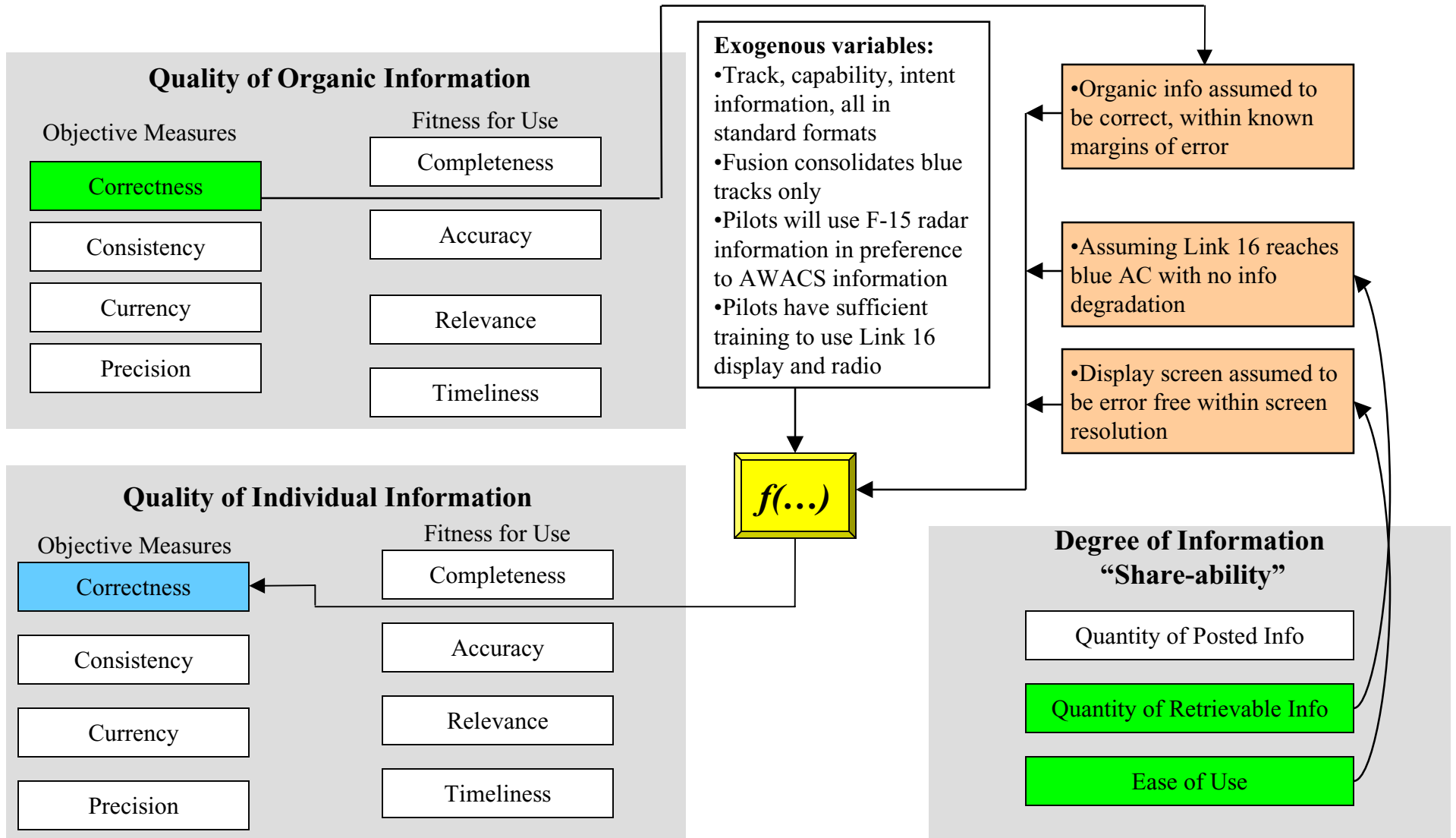


Computing Correctness for Individual Information: Voice Only



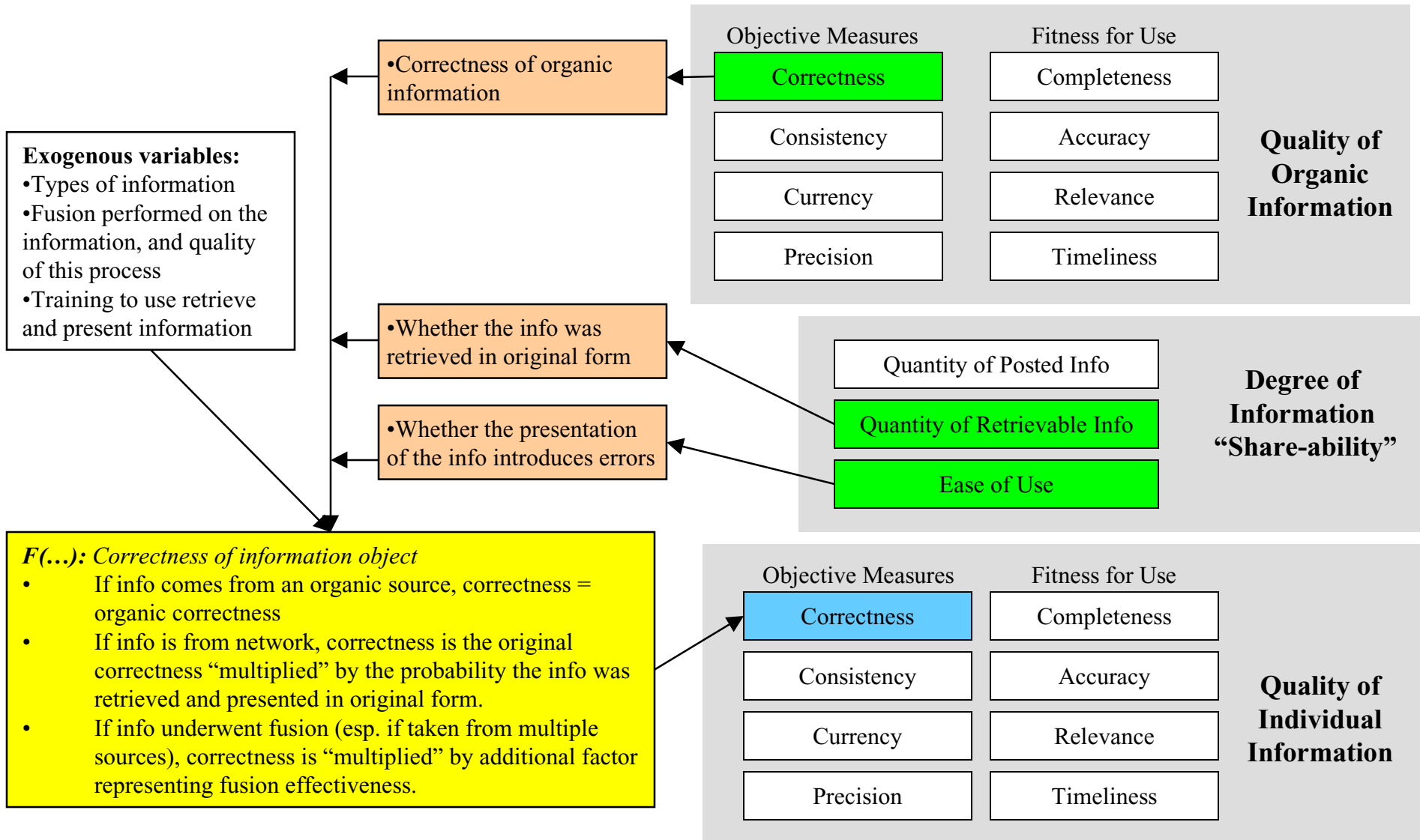


Computing Correctness for Individual Information: Link 16



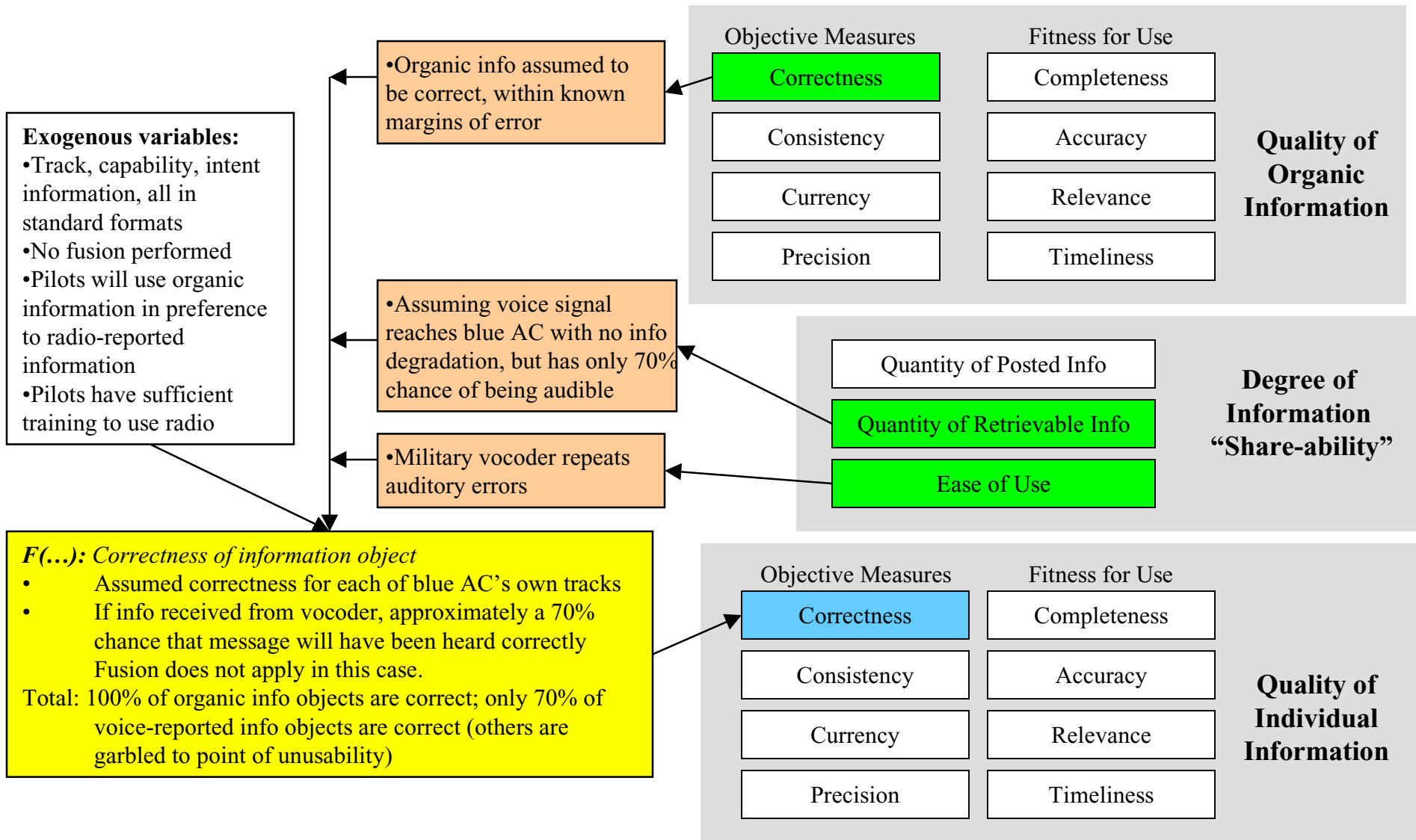


Computing Correctness for Individual Information: Detailed Function



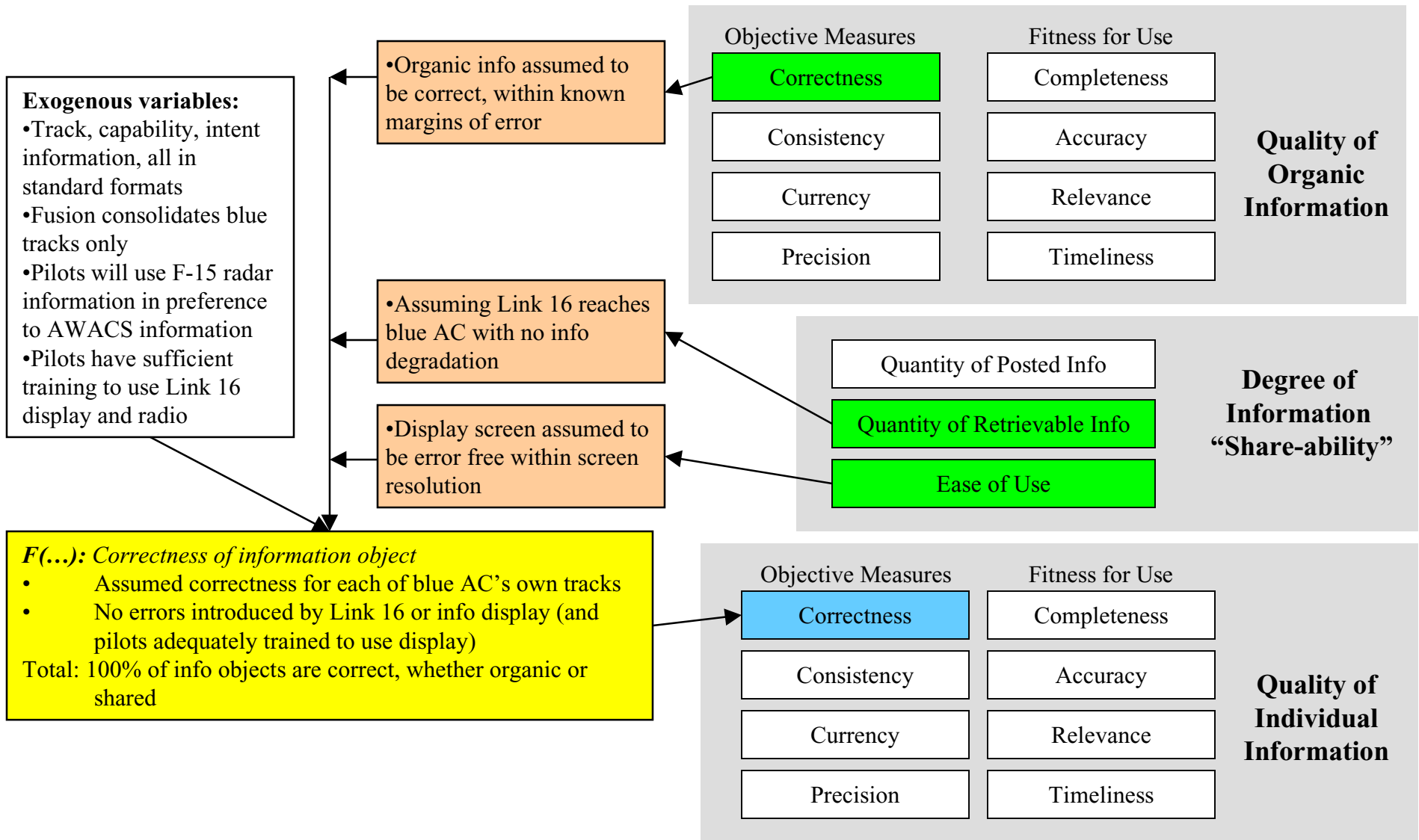


Computing Correctness for Individual Information: Detailed Function, Voice Only



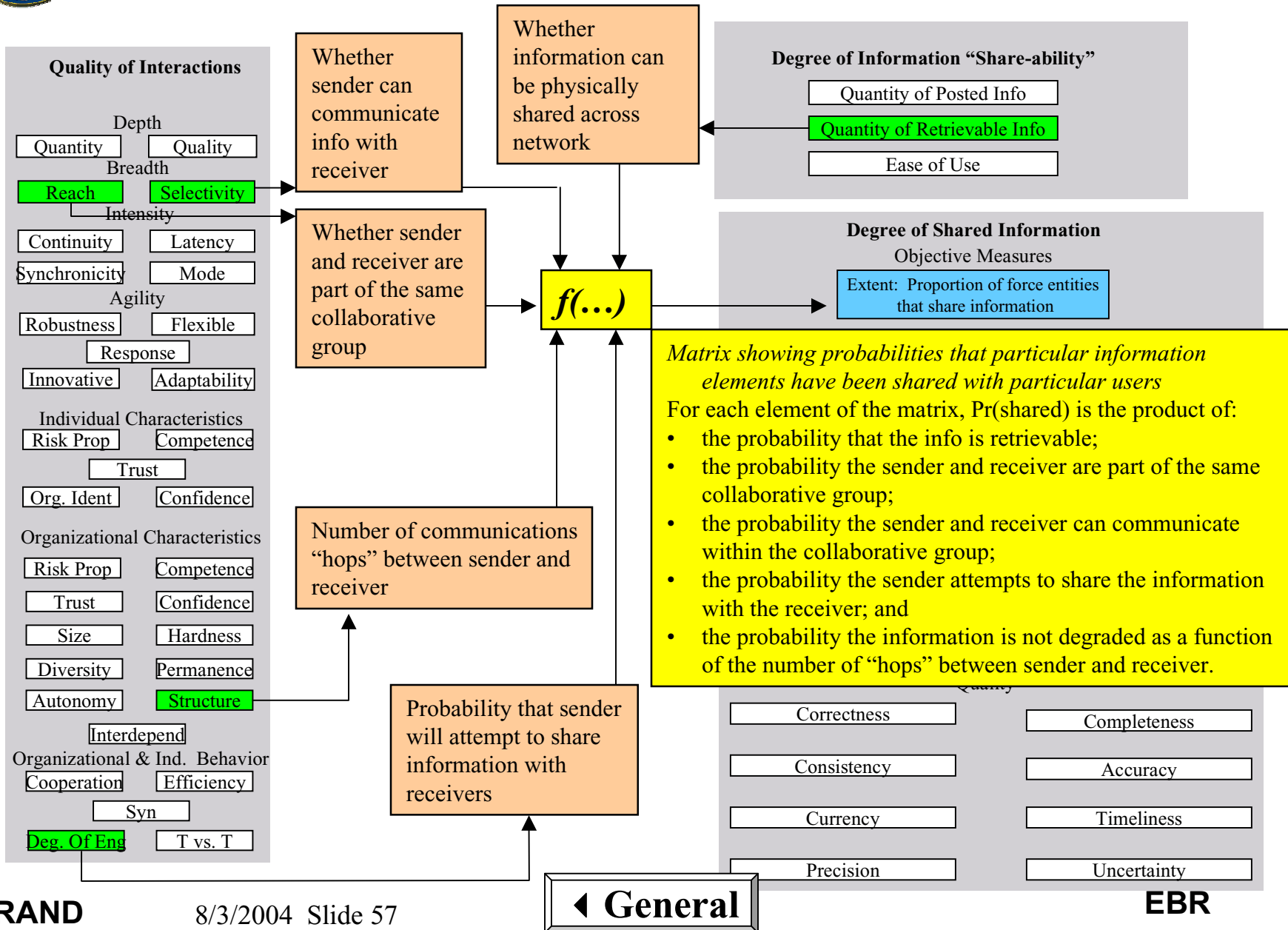


Computing Correctness for Individual Information: Detailed Function, Link 16



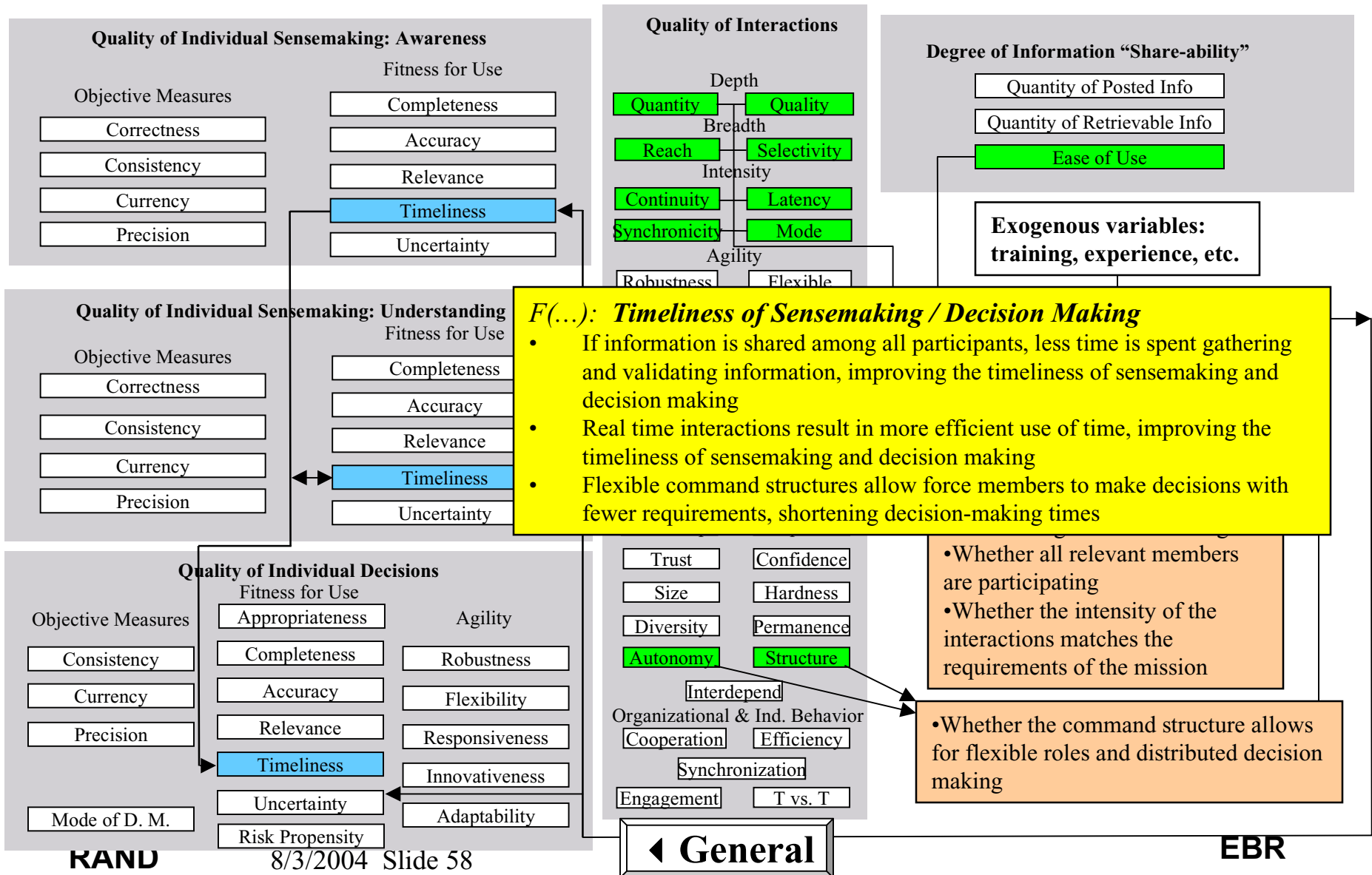


Computing Extent of Shared Information: Detailed Function



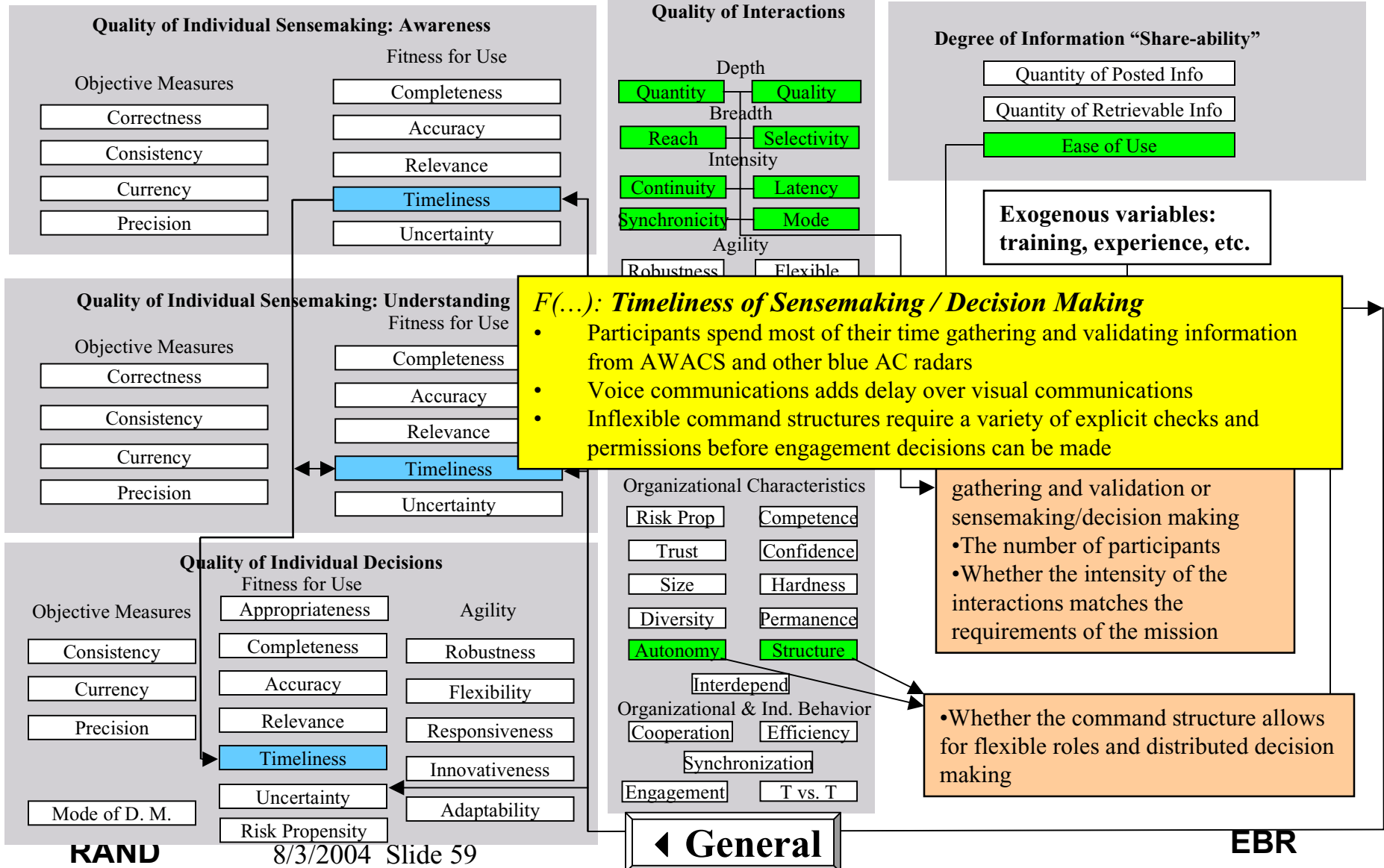


Quality of Individual Sensemaking and Decision Making: Timeliness (Qualitative)





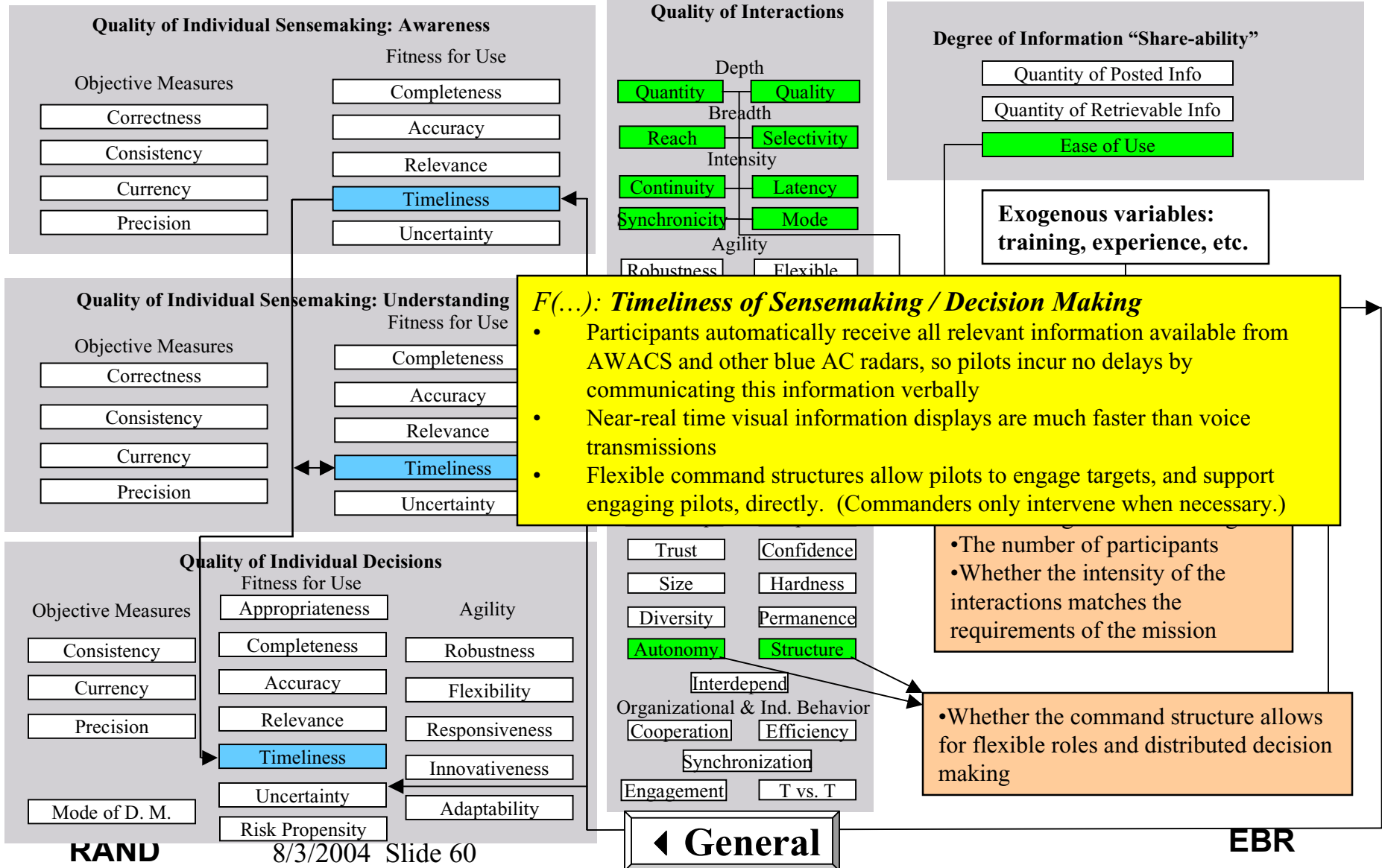
Quality of Individual Sensemaking and Decision Making: Timeliness Voice Only (Qualitative)





Quality of Individual Sensemaking and Decision Making: Timeliness

Link 16 (Qualitative)





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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

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



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Degree of Information “Share-ability”

The degree to which information could be shared among force entities

Attribute	Definition	<i>Attribute Summary</i> <i>(Click Here)</i>	<i>Metrics</i> <i>(Click Here)</i>
Quantity of Posted Information	Extent to which collected information is posted		
Quantity of Retrievable Information	Proportion of nodes that can retrieve various sets of information. Determined by the following: <ul style="list-style-type: none">• Awareness of Information: Degree to which the existence of the information is advertised to force member• Access to Information: Degree to which access to information is controlled• Meta-data of Information: Degree to which information has labels describing what it is and how it may be used (facilitates indexing and searching)		
Ease of Use	Degree to which presentation of information facilitates desired use		



Quality of Individual Information

Information gathered by individuals from the network and organic sources

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



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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

Attribute	Definition	<i>Attribute Summary</i> <i>(Click Here)</i>	<i>Metrics</i> <i>(Click Here)</i>
Objective Measures	Measures quality in reference to criteria that are independent of the situation		
Correctness	Extent to which awareness is consistent with ground truth		
Consistency	Extent to which awareness is internally consistent with prior awareness		
Currency	Time lag of awareness		
Precision	Level of granularity of awareness		
Fitness for Use Measures	Measures quality in reference to criteria that are determined by the situation		
Completeness	Extent to which relevant awareness is obtained		
Accuracy	Appropriateness of precision of awareness for a particular use		
Relevance	Proportion of awareness obtained that is related to task at hand		
Timeliness	Extent to which currency of awareness is suitable to its use		
Uncertainty	Subjective assessment of confidence in awareness		



Quality of Individual Sensemaking: Understanding

Attribute	Definition	<i>Attribute Summary</i> <i>(Click Here)</i>	<i>Metrics</i> <i>(Click Here)</i>
Objective Measures	Measures quality in reference to criteria that are independent of the situation		
Correctness	Extent to which understanding is consistent with ground truth		
Consistency	Extent to which understanding is internally consistent with prior understanding		
Currency	Time lag of understanding		
Precision	Level of granularity of understanding		
Fitness for Use Measures	Measures quality in reference to criteria that are determined by the situation		
Completeness	Extent to which relevant understanding is obtained		
Accuracy	Appropriateness of precision of understanding for a particular use		
Relevance	Proportion of understanding obtained by force member that is related to task at hand		
Timeliness	Extent to which currency of understanding is suitable to its use		
Uncertainty	Subjective assessment of confidence in understanding		



Quality of Individual Decisions I

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

Attribute	Definition	<i>Attribute Summary (Click Here)</i>
Objective Measures	Measures quality in reference to criteria that are independent of the situation	
Consistency	Extent to which decisions are internally consistent with prior understanding and decisions	
Currency	Time lag of decisions	
Precision	Level of granularity of decisions	
Fitness for Use Measures	Measures quality in reference to criteria that are determined by the situation	
Appropriateness	Extent to which decisions are consistent with existing understanding, command intent and values	
Completeness	Extent to which relevant decisions encompass the necessary: <ul style="list-style-type: none"> •Depth: range of actions and contingencies included •Breadth: range of force elements included •Time: range of time horizons included 	
Accuracy	Appropriateness of precision of decisions for a particular use	
Relevance	Proportion of decisions that are significant to task at hand	
Timeliness	Extent to which currency of decision making is suitable to its use	
Uncertainty	Subjective assessment of confidence in decisions	
Risk Propensity	Extent of risk aversion	
Mode of Decision Making	Type of decision making process utilized (naturalistic, dominated, min-max, expected utility)	



Quality of Individual Decisions II

Attribute	Definition	<i>Attribute Summary</i> <i>(Click Here)</i>
Agility		
Robustness	Degree to which decision is dominant across a range of situations and degradation conditions	
Flexibility	Degree to which decision allows force entities to maintain flexibility (i.e., incorporates multiple ways of succeeding)	
Responsiveness	Degree to which decision is relevant and timely	
Innovativeness	Degree to which decision reflects novel ways to perform known tasks and/or develops new ways of doing novel tasks	
Adaptability	Degree to which decision facilitates force entities' ability to alter the decision, decision making participants and/or decision making process and implement appropriate modifications	



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

Attributes	Definitions	<i>Attribute Summary</i> <i>(Click Here)</i>
Risk Propensity	Extent of risk aversion	
Competence	Level of knowledge, skills, abilities, and attitudes (KSAAAs)	
Trust	Extent to which individual is willing to rely on other members	
Organizational Identification	Extent to which individual's identities align with organizational identities	
Confidence	Degree of individual's expectation that other members are reliable	



Quality of Interactions

Contributing Attributes: Organizational Characteristics

Attributes	Definitions	<i>Attribute Summary</i> <i>(Click Here)</i>
Risk Propensity	Extent of risk aversion	
Competence	Distribution of members knowledge, skills, abilities and attitudes (KSAAAs)	
Trust	Extent to which members are willing to rely on one another	
Confidence	Extent to which members have expectations of the reliability of the organization	
Size	Number of team members involved	
Hardness	Degree to which team members have interacted in the past on the same task	
Diversity	Degree to which team members are heterogeneous or homogeneous across exogenous variables: experience, age, gender, etc.	
Permanence	Expected duration of organization	
Autonomy	Extent to which organization is externally or self directed	
Structure	Distribution of peer and authority relationships <ul style="list-style-type: none">• Layers of authority• Functional Differentiation• Connectedness within and across layers• Directness of connections	
Interdependence	Extent to which members depend on one another for resources (materials, KSAAAs, etc.)	



Quality of Interactions Contributing Attributes: Organizational and Individual Behaviors

Attributes	Definitions	<i>Attribute Summary</i> <i>(Click Here)</i>
Cooperation	Extent to which member(s) are willing and able to work together	
Efficiency	Extent to which members utilize one another's resources so as to minimize costs and maximize benefits	
Synchronization	Extent to which organization is conflicted, deconflicted, or synergistic	
Engagement	Extent to which all members actively and continuously participate	
Team vs. Task Balance	Extent to which efforts are directed to organizational issues vs. relating to the objective	



Degree of Shared Information

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



Degree of Shared Sensemaking: Shared Understanding

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



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DEFINITION OF METRICS



Quality of Organic Information

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

Attribute	Metrics	<i>Attribute Summary</i> <i>(Click Here)</i>	<i>Definitions</i> <i>(Click Here)</i>
Objective Measures	Measures quality in reference to criteria that are independent of the situation		
Correctness	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.)		
Consistency	Degree of 'deviation' from previous information		
Currency	Age of information		
Precision	Level of measurement detail of information item		
Fitness for Use Measures	Measures quality in reference to criteria that are determined by the situation		
Completeness	Percentage of ground truth relevant and needed information collected		
Accuracy	Degree to which precision matches what is needed (0=no match, 10=high degree of matching between precision level needed and available)		
Relevance	Proportion of information collected that is related to task at hand		
Timeliness	Degree to which currency matches what is needed (0=no match, 10=high degree of matching between currency level needed and available)		



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Degree of Information “Share-ability”

The degree to which information could be shared among force entities

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



Quality of Individual Information

Information gathered by individuals from the network and organic sources

Attribute	Metrics	<i>Attribute Summary</i> <i>(Click Here)</i>	<i>Definitions</i> <i>(Click Here)</i>
Objective Measures	Measures quality in reference to criteria that are independent of the situation		
Correctness	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.)		
Consistency	Degree of 'deviation' from previous information		
Currency	Age of information		
Precision	Level of measurement detail of information item		
Fitness for Use Measures	Measures quality in reference to criteria that are determined by the situation		
Completeness	Percentage of ground truth relevant and needed information		
Accuracy	Degree to which precision matches what is needed (0=no match, 10=high degree of matching between precision)		
Relevance	Proportion of information that is related to task at hand		
Timeliness	Degree to which currency matches what is needed (0=no match, 10=high degree of matching between currency level needed and available)		



Quality of Individual Sensemaking: Awareness

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



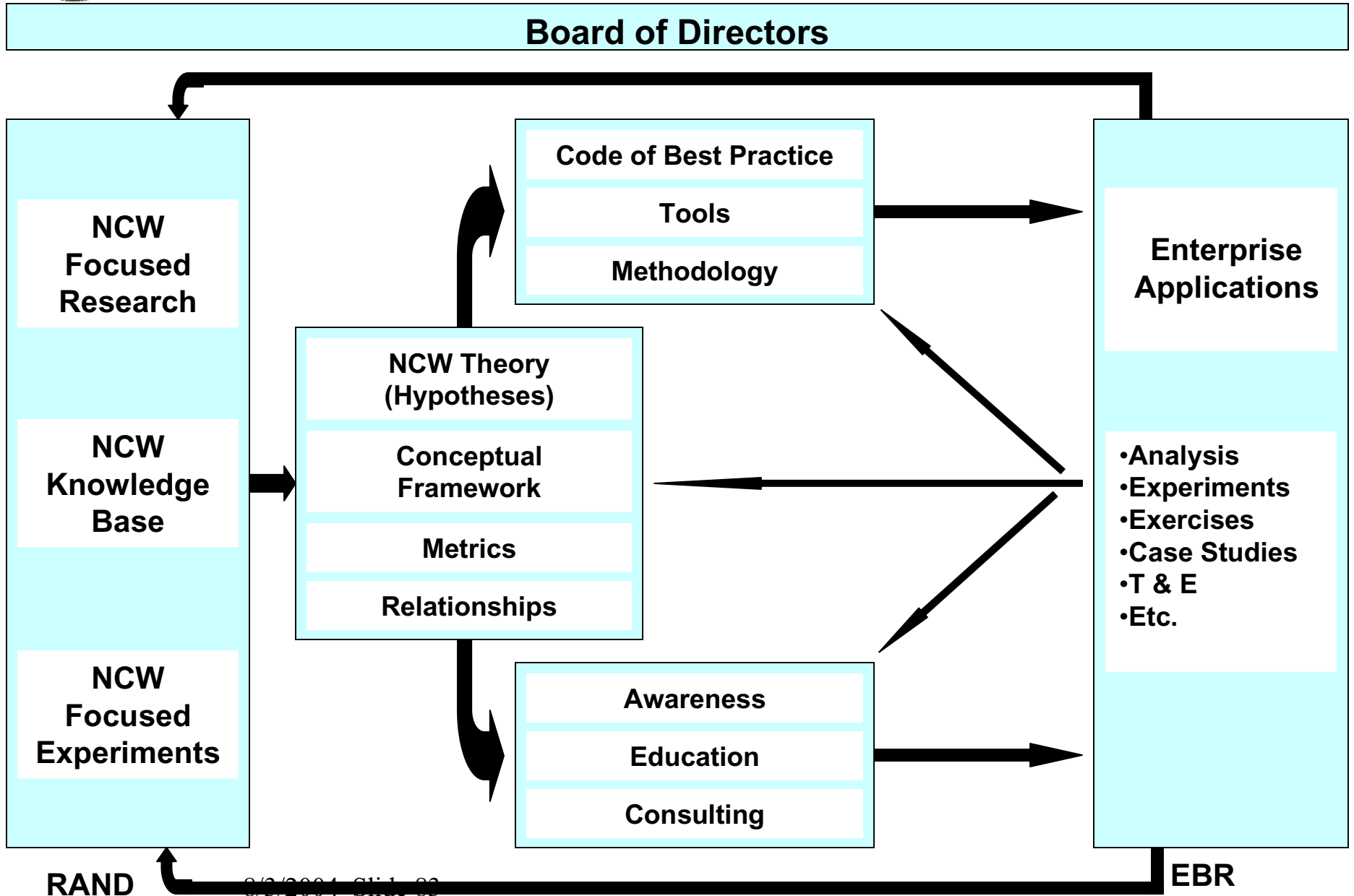
Quality of Individual Sensemaking: Understanding

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



The NCW Framework Initiative

Key To Developing and Applying NCW Theory Across DoD Enterprise





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



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Application of the NCW Framework to Air-to-Air Combat

- **Objectives**

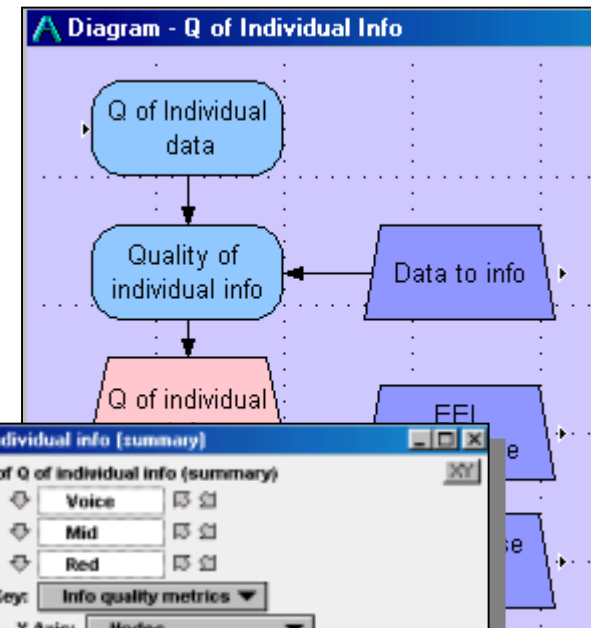
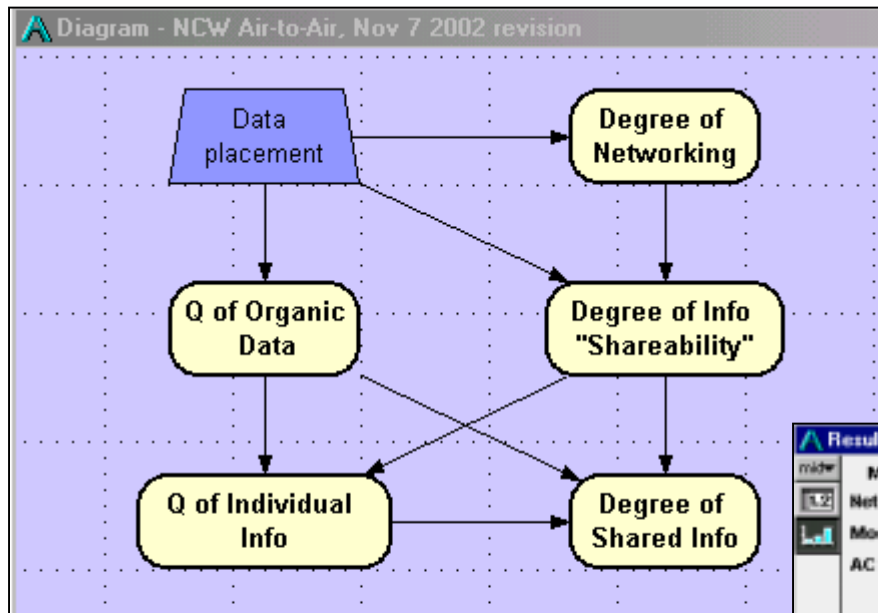
- Gain insight into how NCW is a new source of power in Air-to-Air combat
- Illuminate contribution of enabling capabilities in the NCW value chain
- Identify areas where data is needed
- Assess utility of framework and identify needed improvements

- **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



Object - Q of individual info (summary)

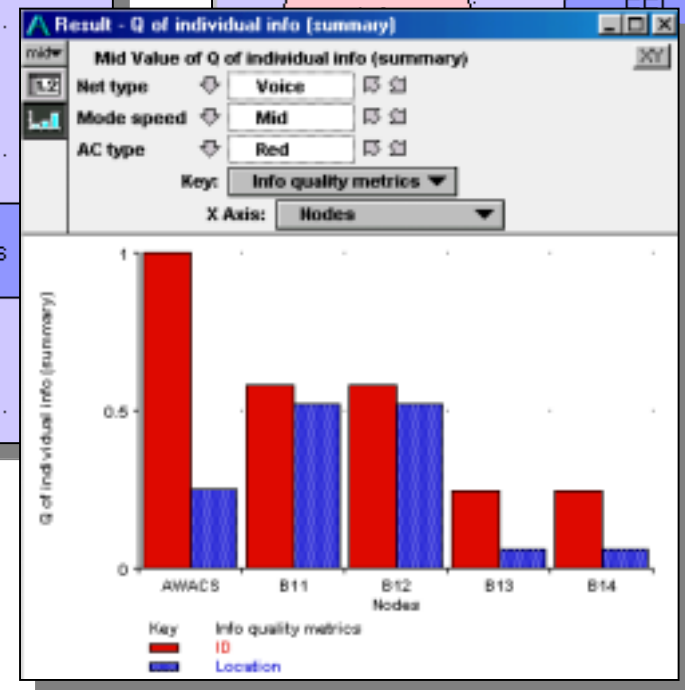
Here, we assign targeting-level info to have a value of 1, and cue-only-level info to have a value of 0.25

expr

Definition: $\text{sum}(\max(Q_of_individual_info * \text{Time_to_use_weights}, \text{Time_to_use_levels}) * \text{Eei_red_or_blue}, \text{EEIs}) / \text{sum}(\text{Eei_red_or_blue}, \text{EEIs})$

Inputs:

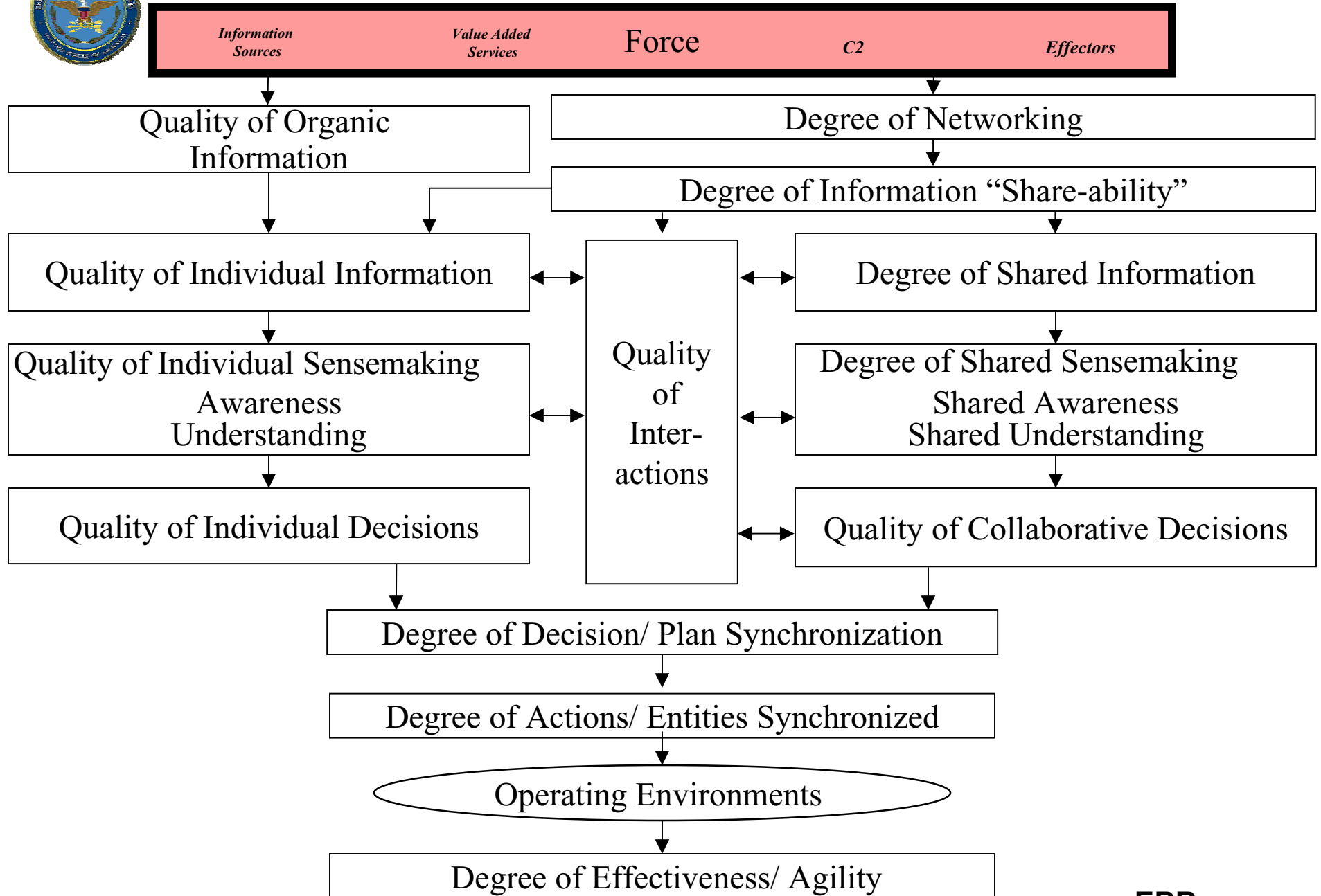
- Eeis EEIs
- Eei_red_... EEI red-or-blue
- Q_of_indi... Quality of individual info
- Time_to_... Time-to-use levels
- Time_to_... Time-to-use weights





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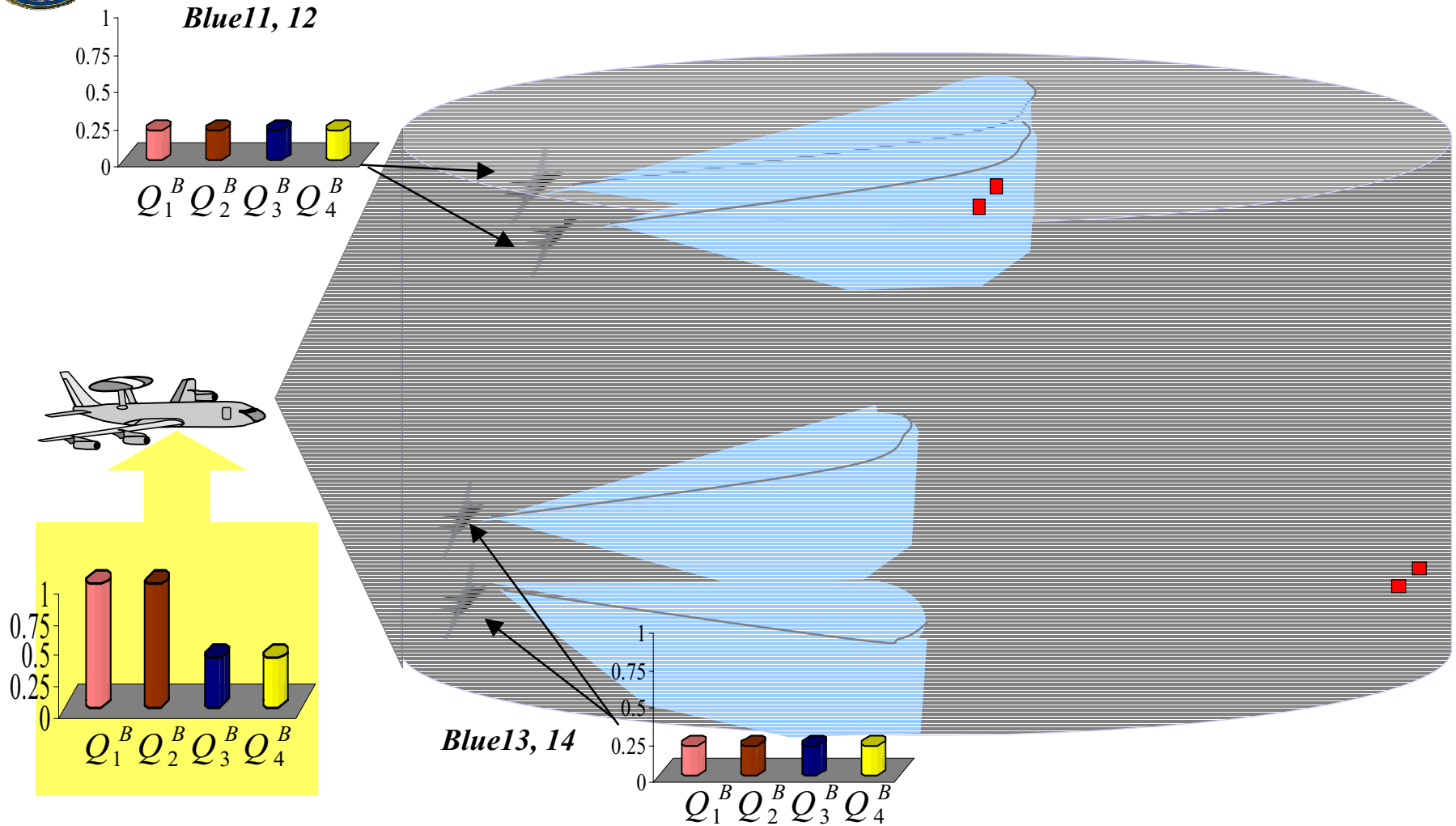
NCW Conceptual Framework





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Quality of Organic Information: Blue Tracks



Q_1^B : *Completeness: Detection*

Q_3^B : *Correctness: Location*

Q_2^B : *Correctness: ID*

Q_4^B : *Correctness: Velocity*



Influence of Networking on Information “Share-ability”

Force

Information. Sources

Value Added Services

C2

Effectors

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

Quality
of
Interactions

Degree of Information “Share-ability”

Quantity of Posted Info

Quantity of Retrievable Info

Ease of Use

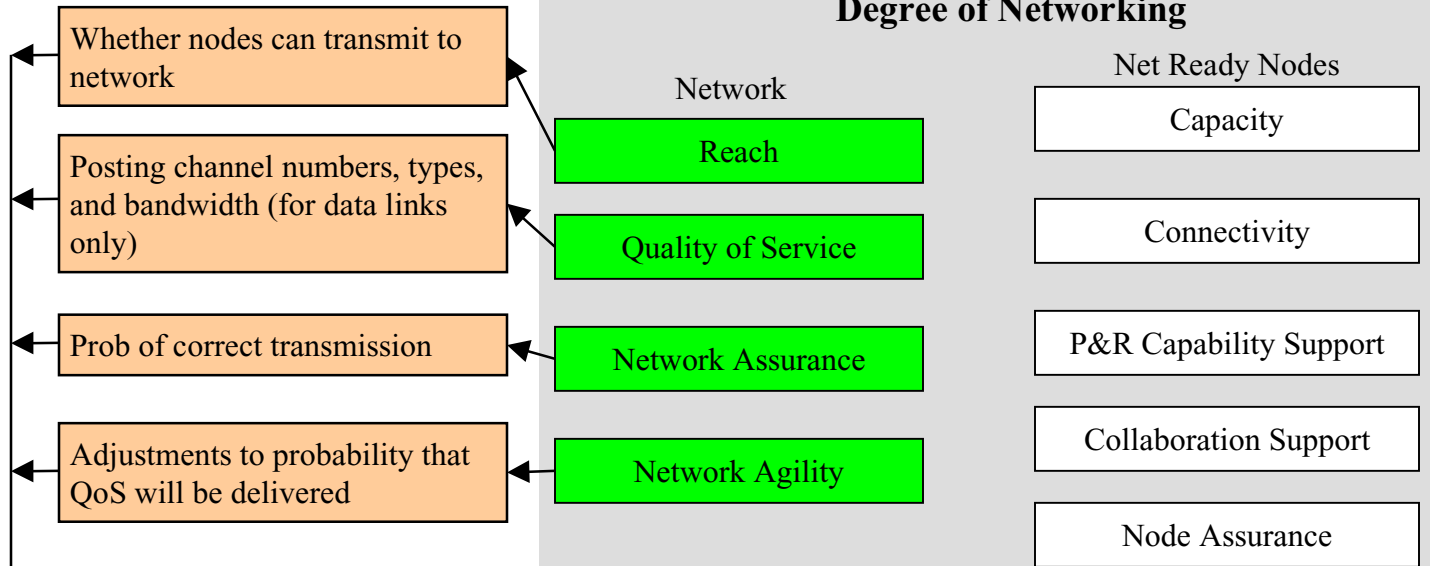


Computing Quantity of Posted Info

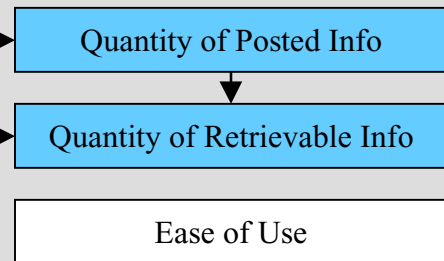
Force



Degree of Networking

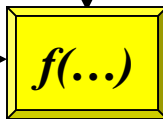


Degree of Information "Share-ability"

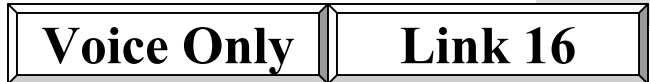


Exogenous variables:

- 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



EBR



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Quantity of Retrieved Information Percent of Organic Information Retrieved

Voice Only

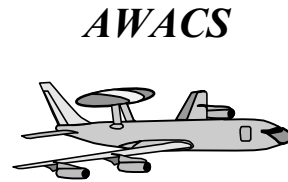
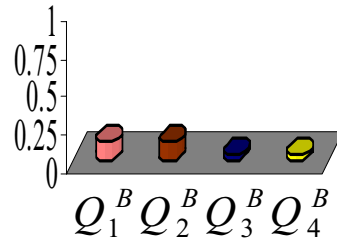
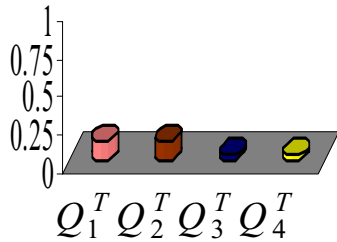
Link 16 + Voice

Threat Tracks

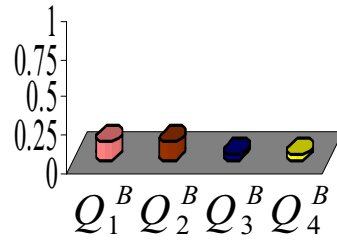
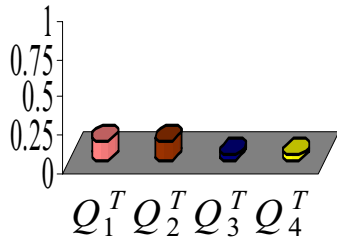
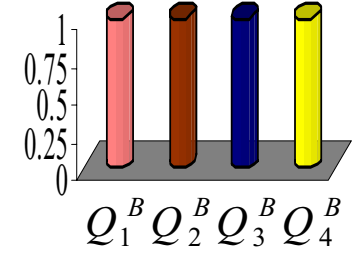
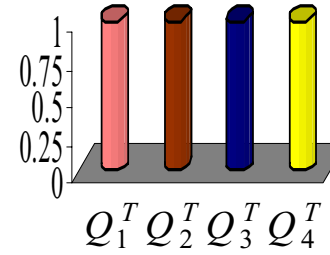
Blue Tracks

Threat Tracks

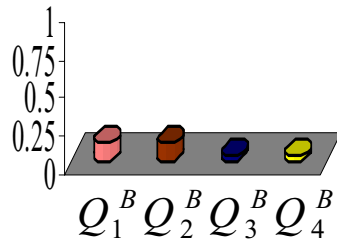
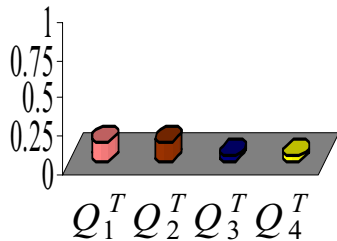
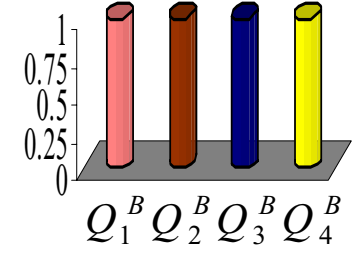
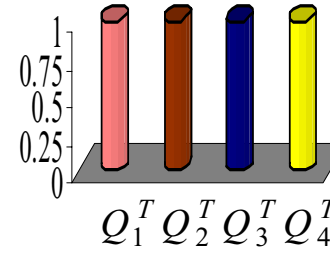
Blue Tracks



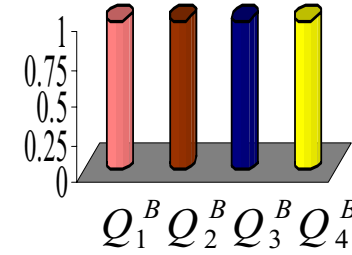
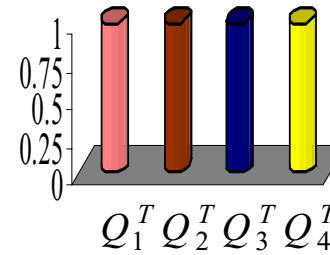
AWACS



Blue 11 & 12



Blue 13 & 14



Q_1 *Completeness: Detection*

Q_3 *Correctness: Location*

Q_2 *Correctness: ID*

Q_4 *Correctness: Velocity*

RAND

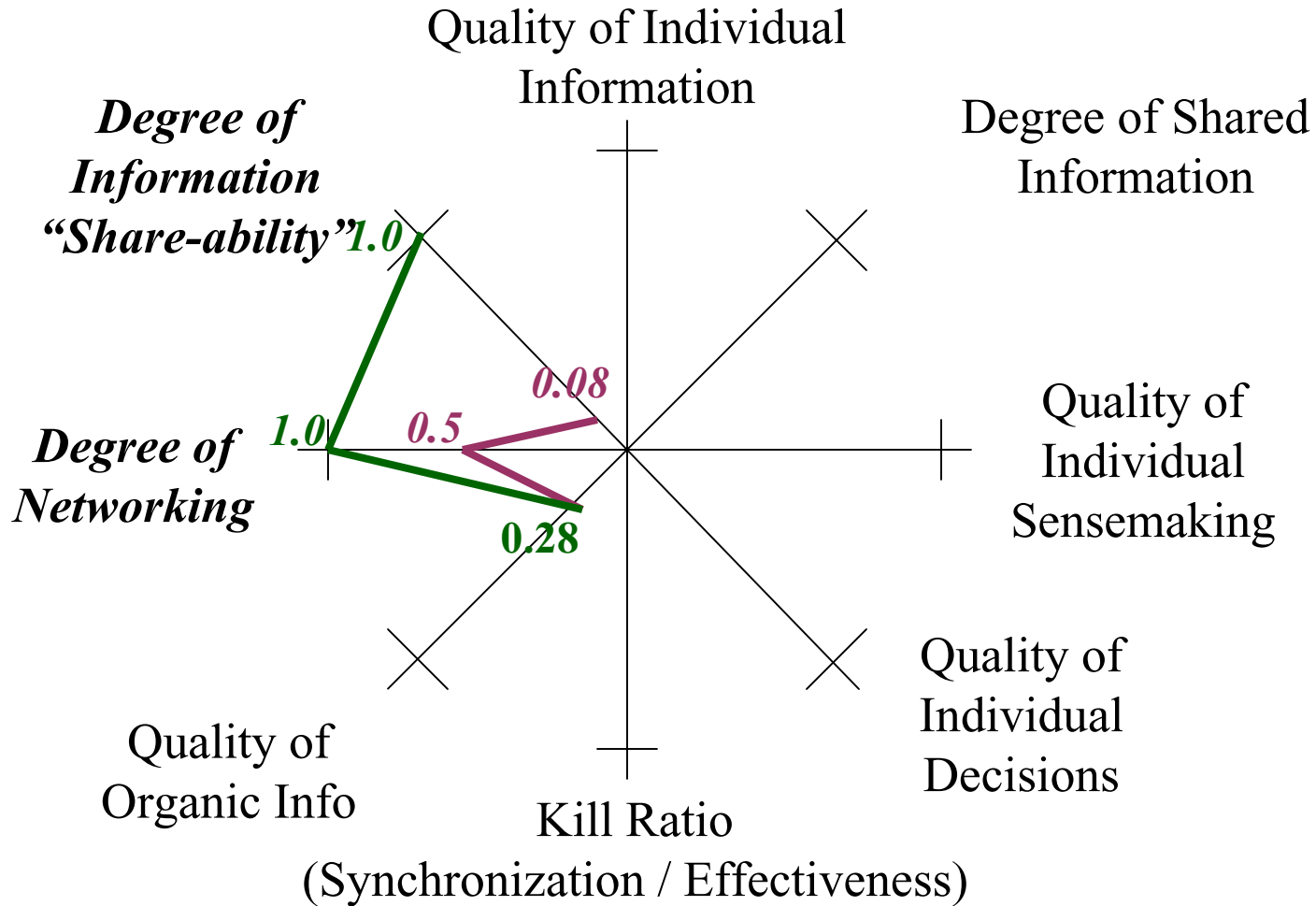
BR



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Comparing MCPs Using Summary Metrics

Degree of Networking and Quantity of Information Retrieved

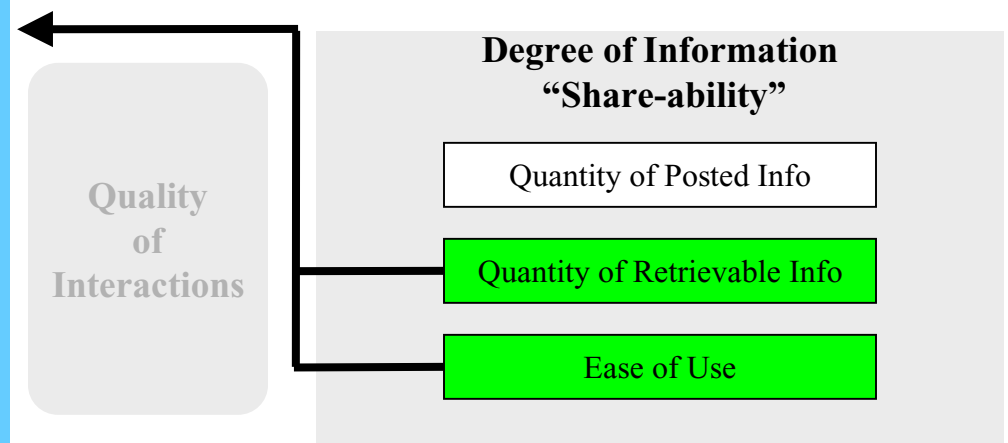
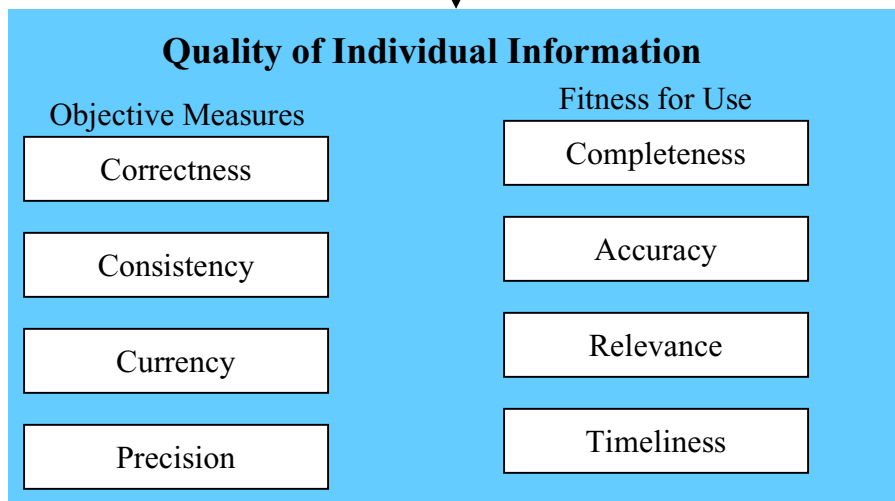
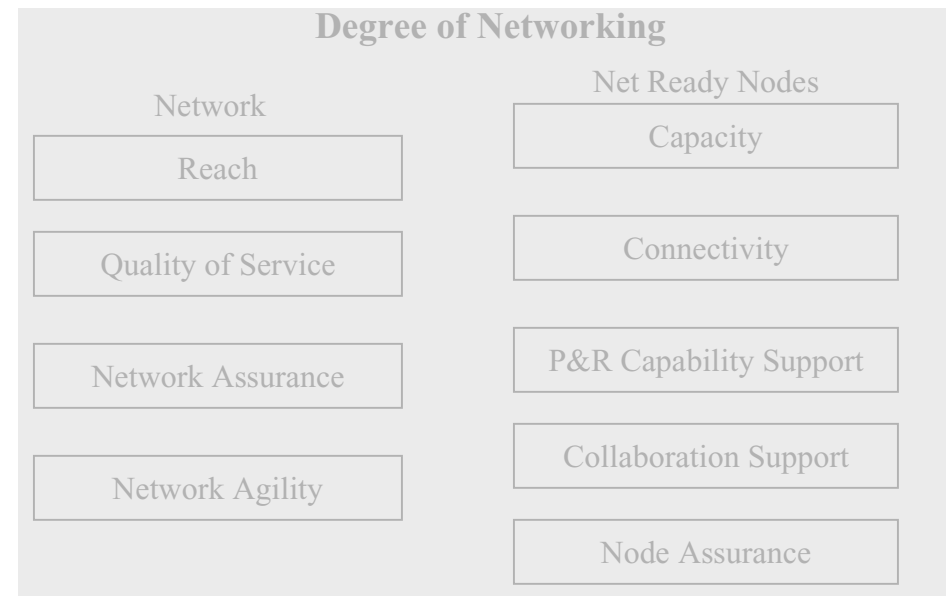
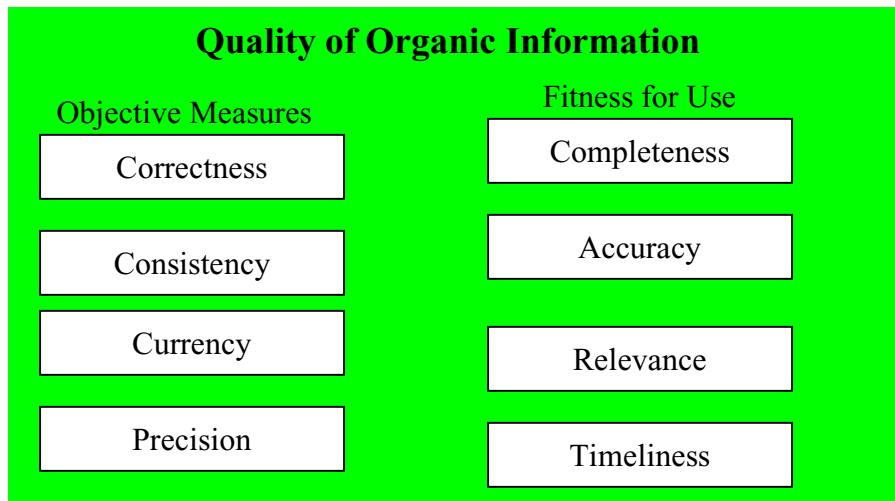


Overall average over information quality dimensions and package members



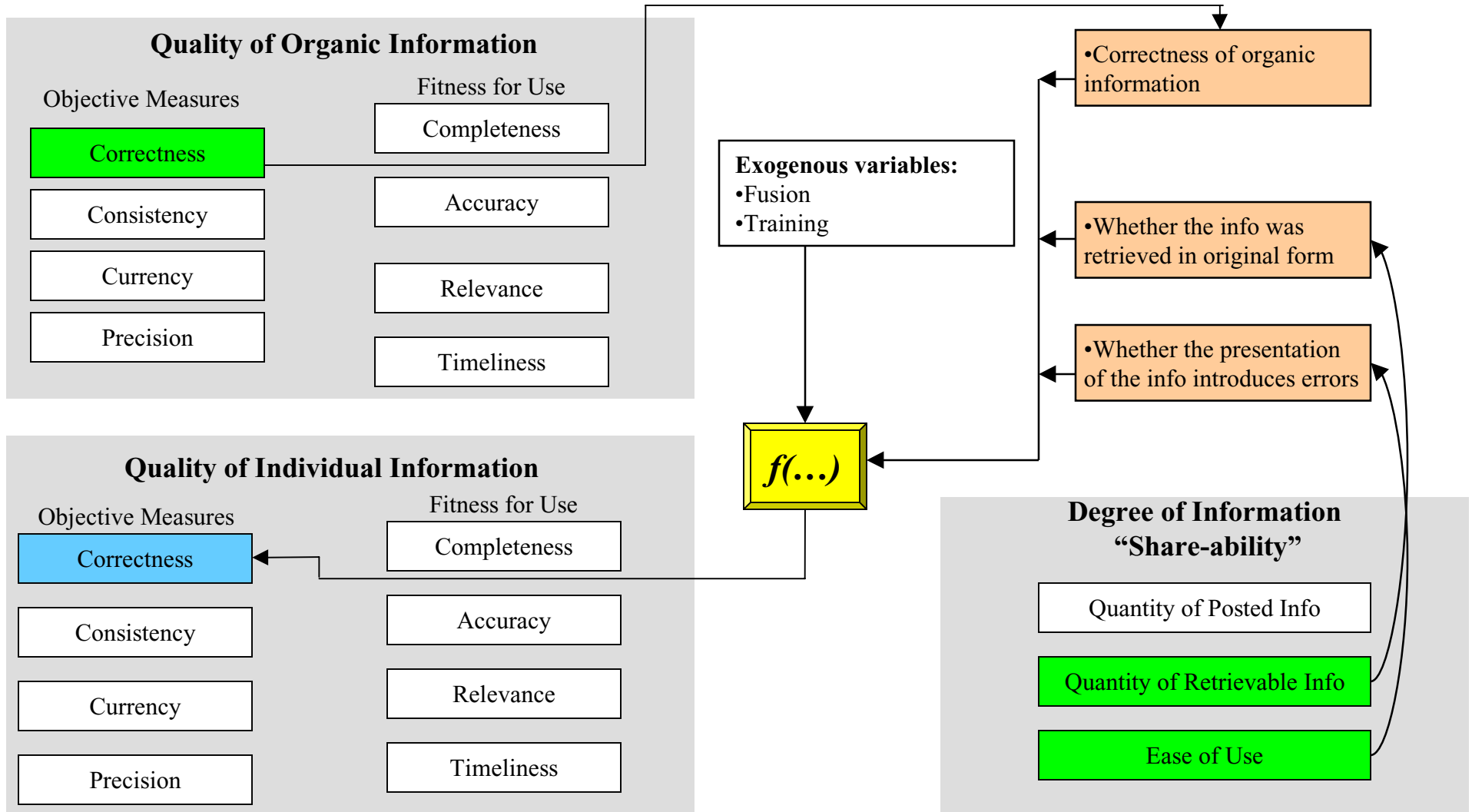
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Influence of Organic Info Quality and Degree of Info Sharing on Quality of Individual Information





Quality of Individual Information: Correctness



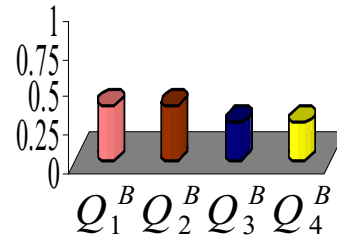
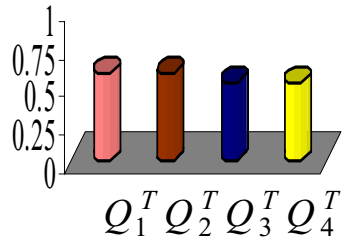
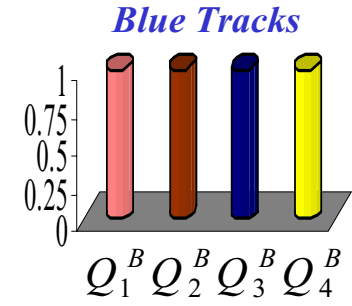
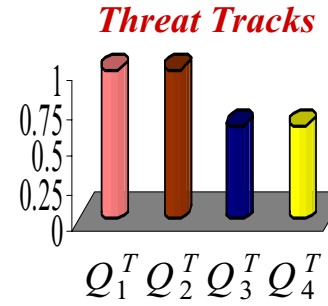
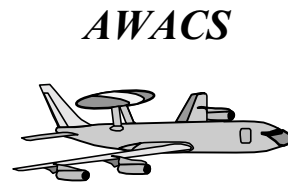
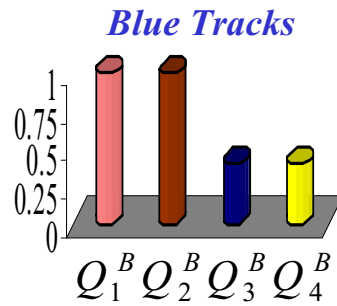
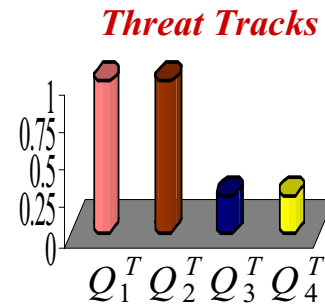


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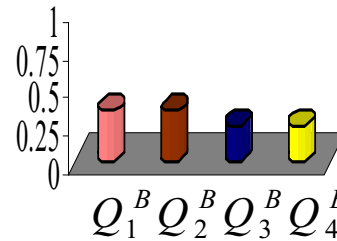
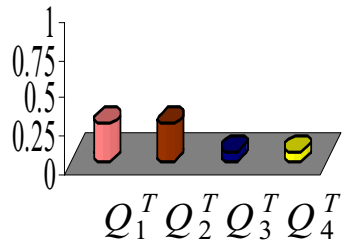
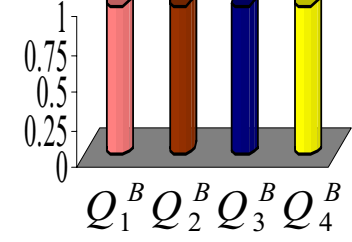
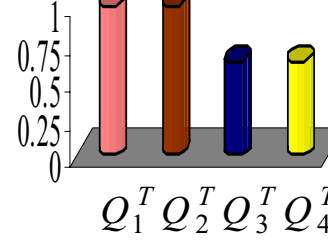
Quality of Individual Information: Voice Only vs. Link 16

Voice Only

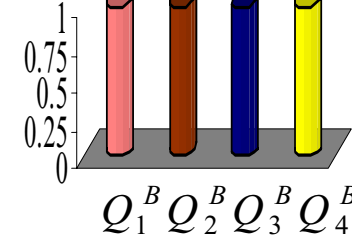
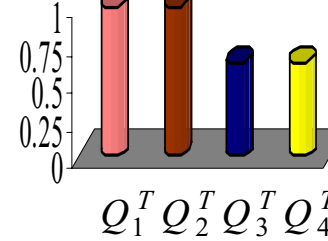
Link 16 + Voice



Blue 11 & 12



Blue 13 & 14



Q_1 **Completeness: Detection**

Q_3 **Correctness: Location**

Q_2 **Correctness: ID**

Q_4 **Correctness: Velocity**

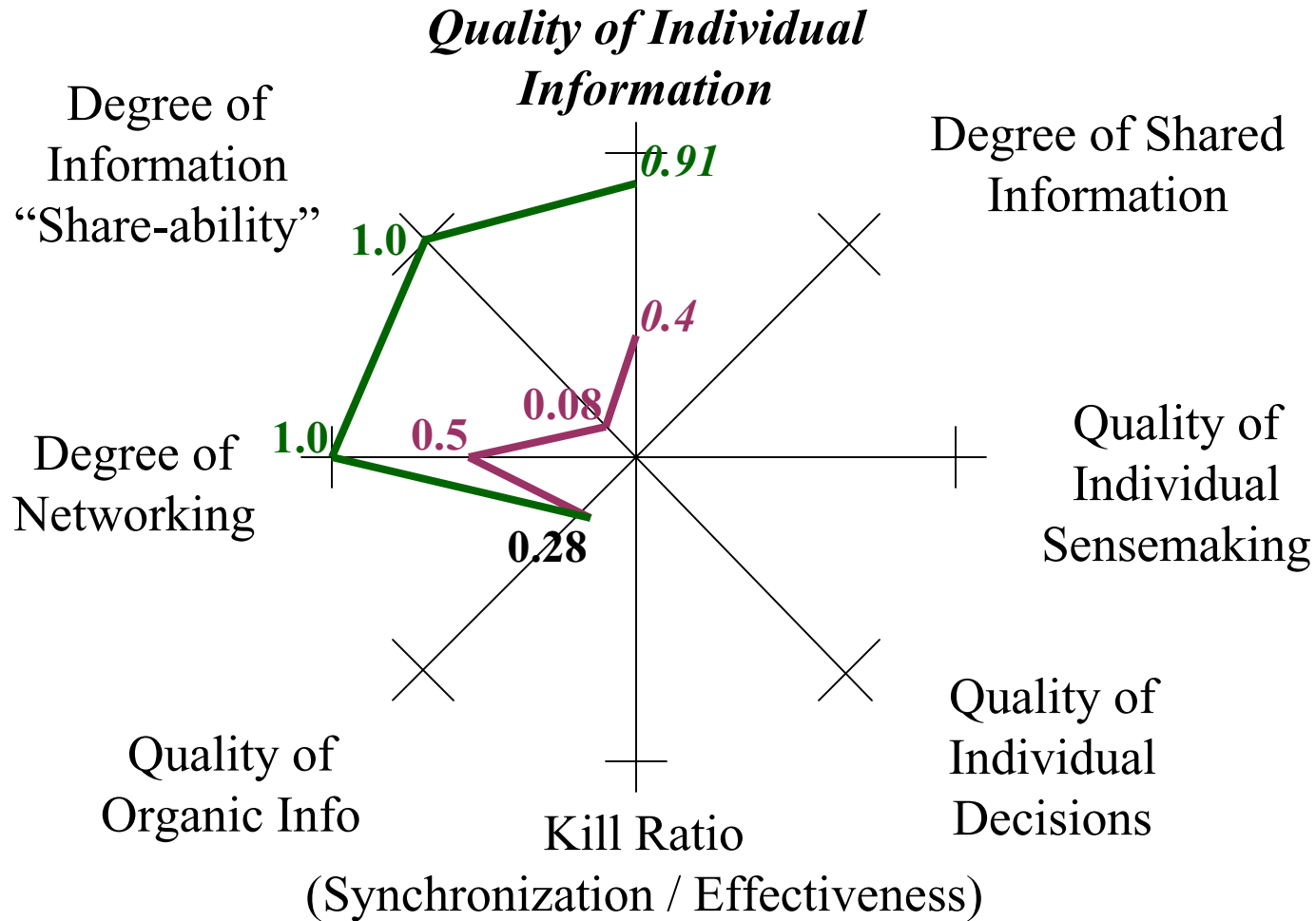
RAND

BR



Comparing MCPs Using Summary Metrics

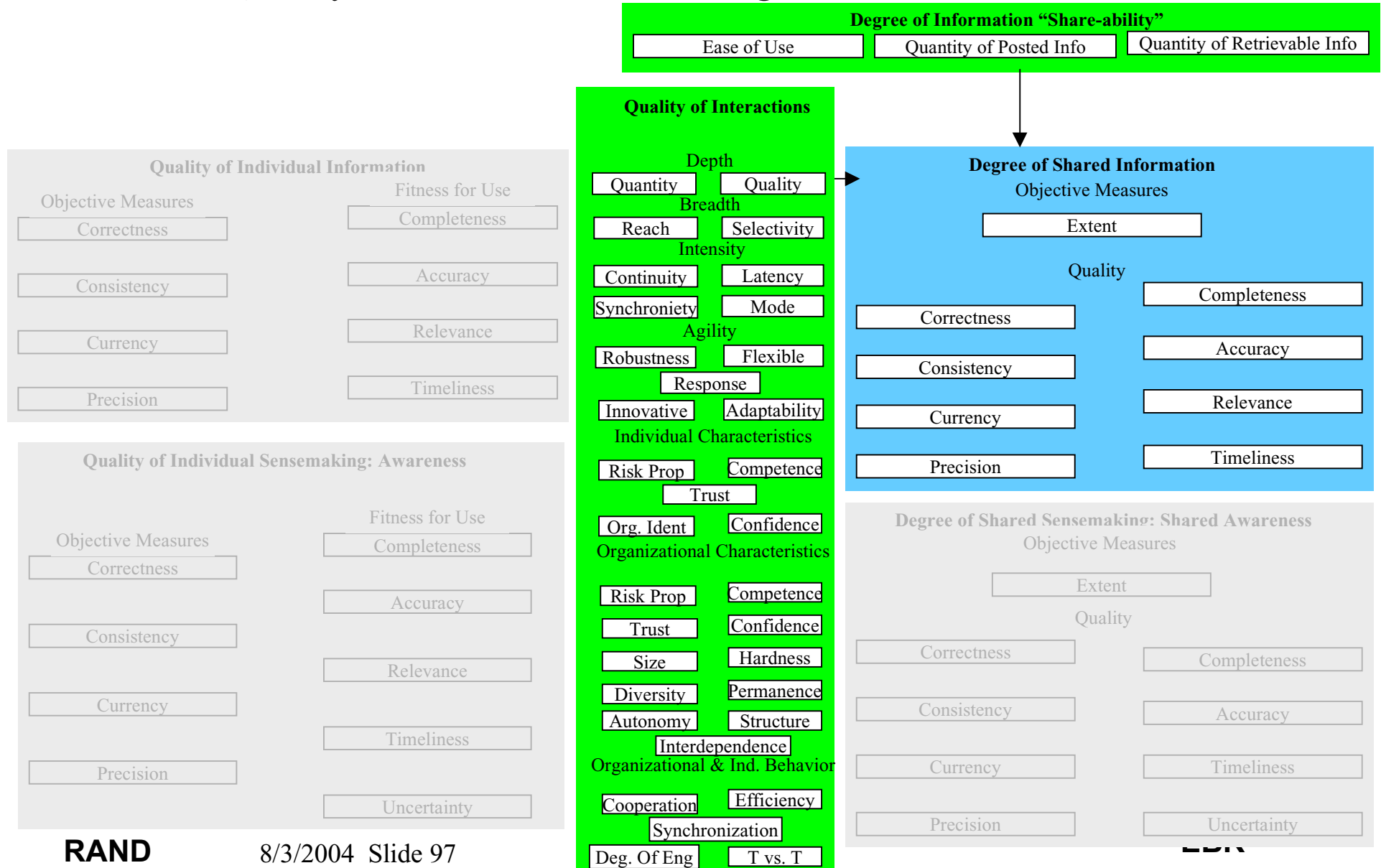
Quality of Individual Information



Overall average over information quality dimensions and package members

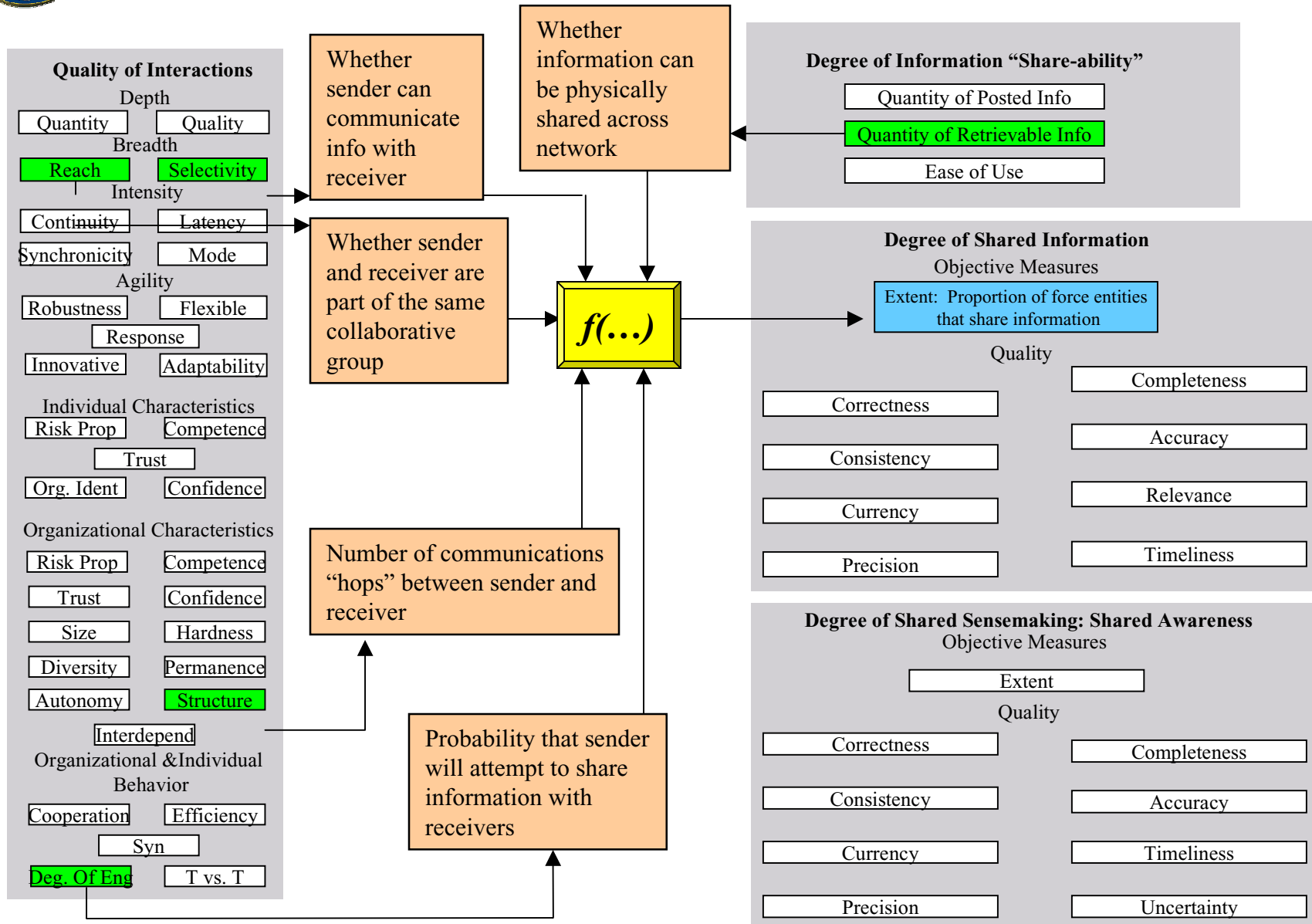


Influence of Information “Share-ability” and Nature and Quality of Interactions on Degree of Shared Information





Computing Extent of Shared Information



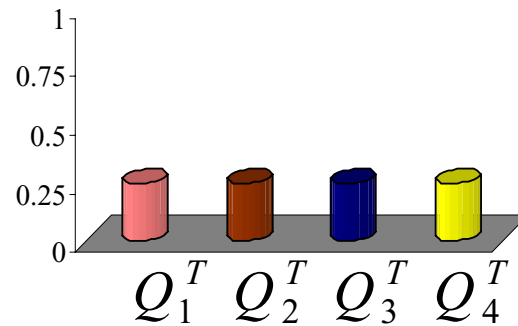


Degree of Shared Information: Extent of Shared Track Information

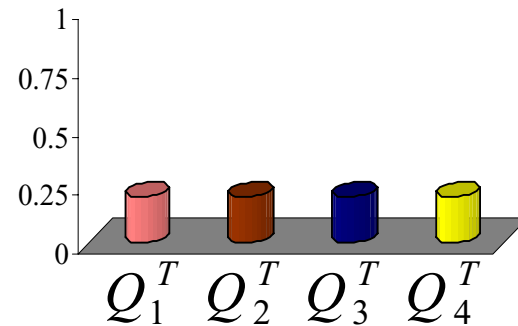
All blue AC have the same shared information in this example (all listen to the same voice channel or receive the same Link 16 broadcasts)

Voice Only

Threat Tracks

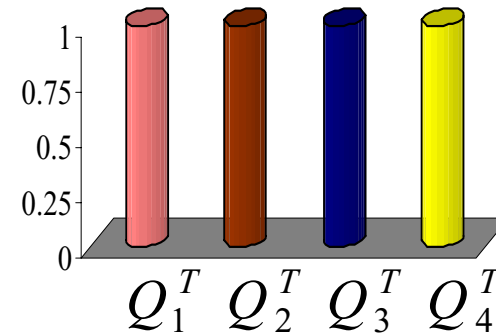


Blue Tracks

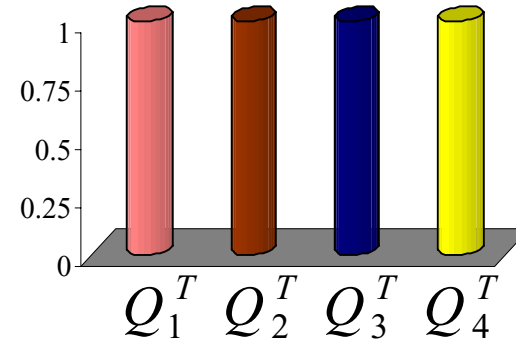


Voice + Link 16

Threat Tracks



Blue Tracks



Q_1 *Completeness: Detection*

Q_2 *Correctness: ID*

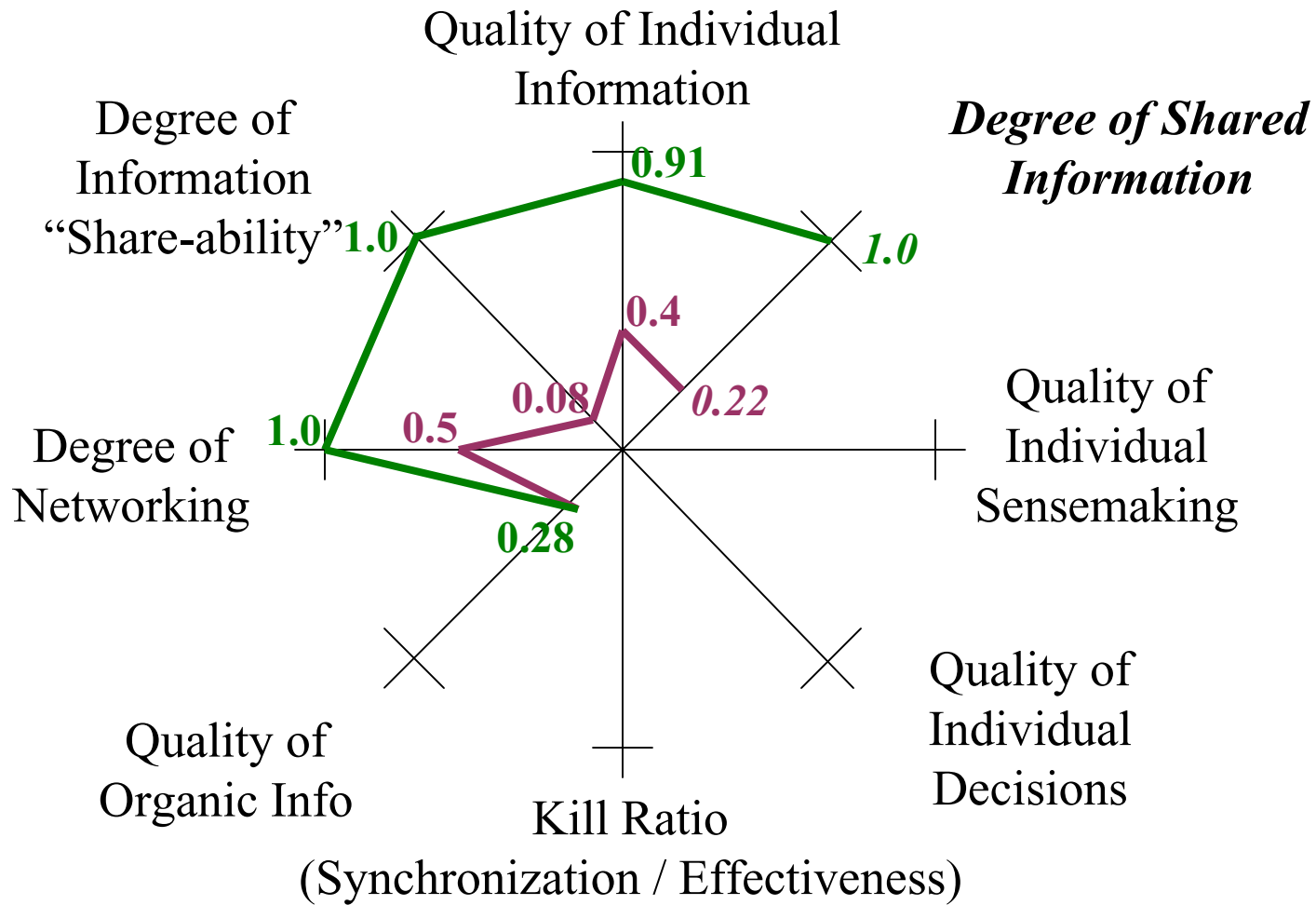
Q_3 *Correctness: Location*

Q_4 *Correctness: Velocity*



Comparing MCPs Using Summary Metrics

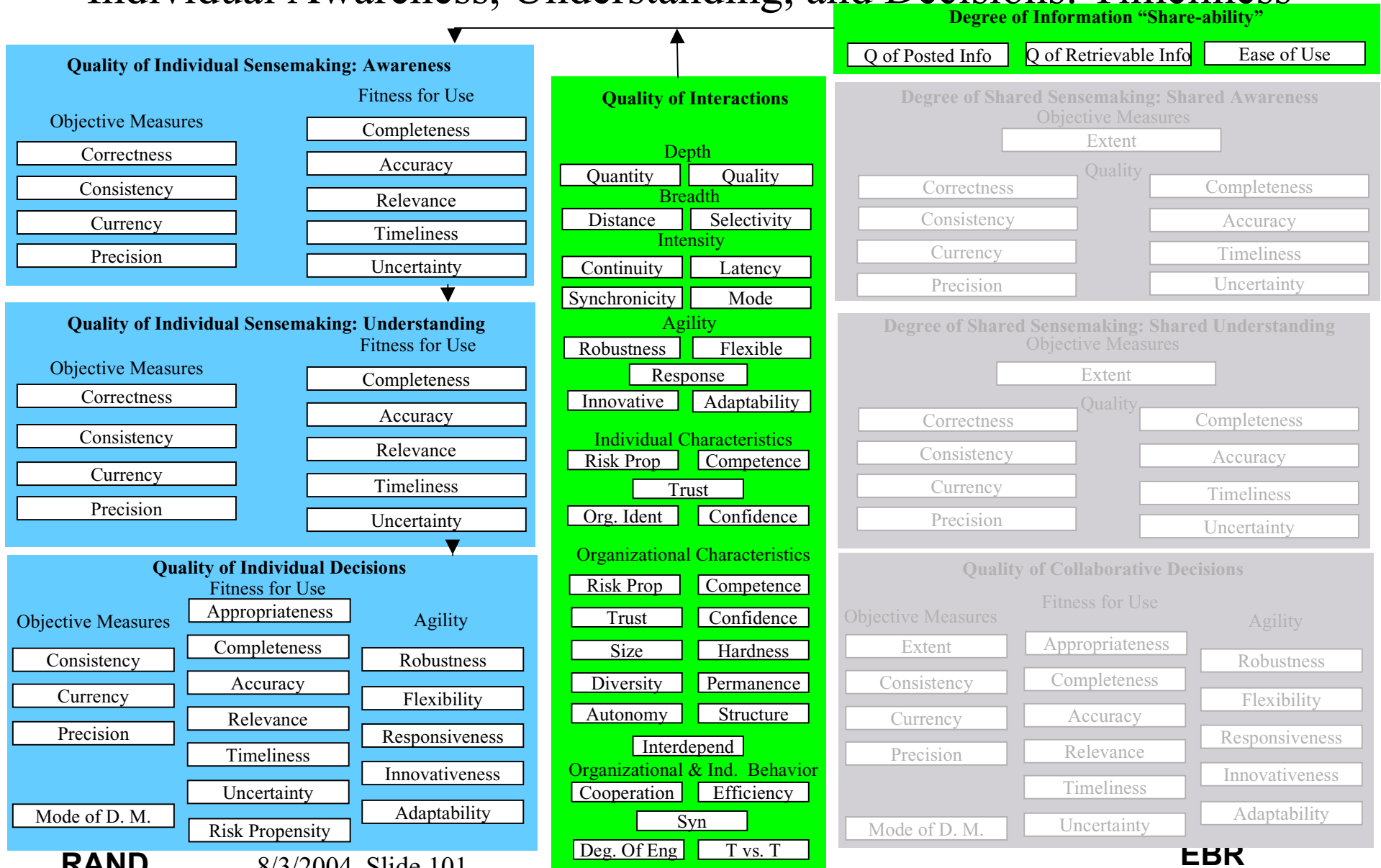
Degree of Shared Information



Overall average over information quality dimensions and package members

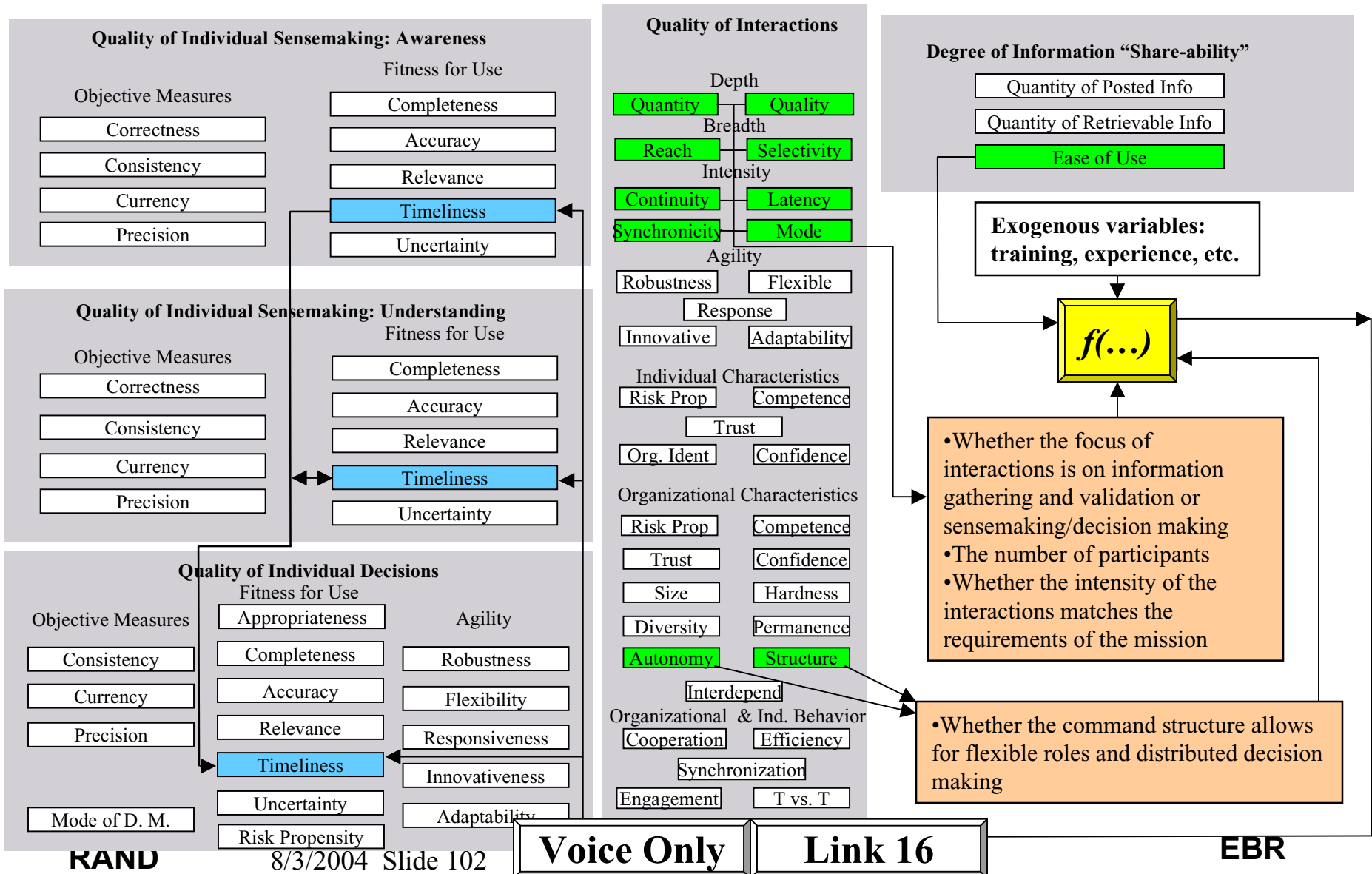


Influence of Information “Share-ability” and Nature and Quality of Interactions on Individual Awareness, Understanding, and Decisions: Timeliness





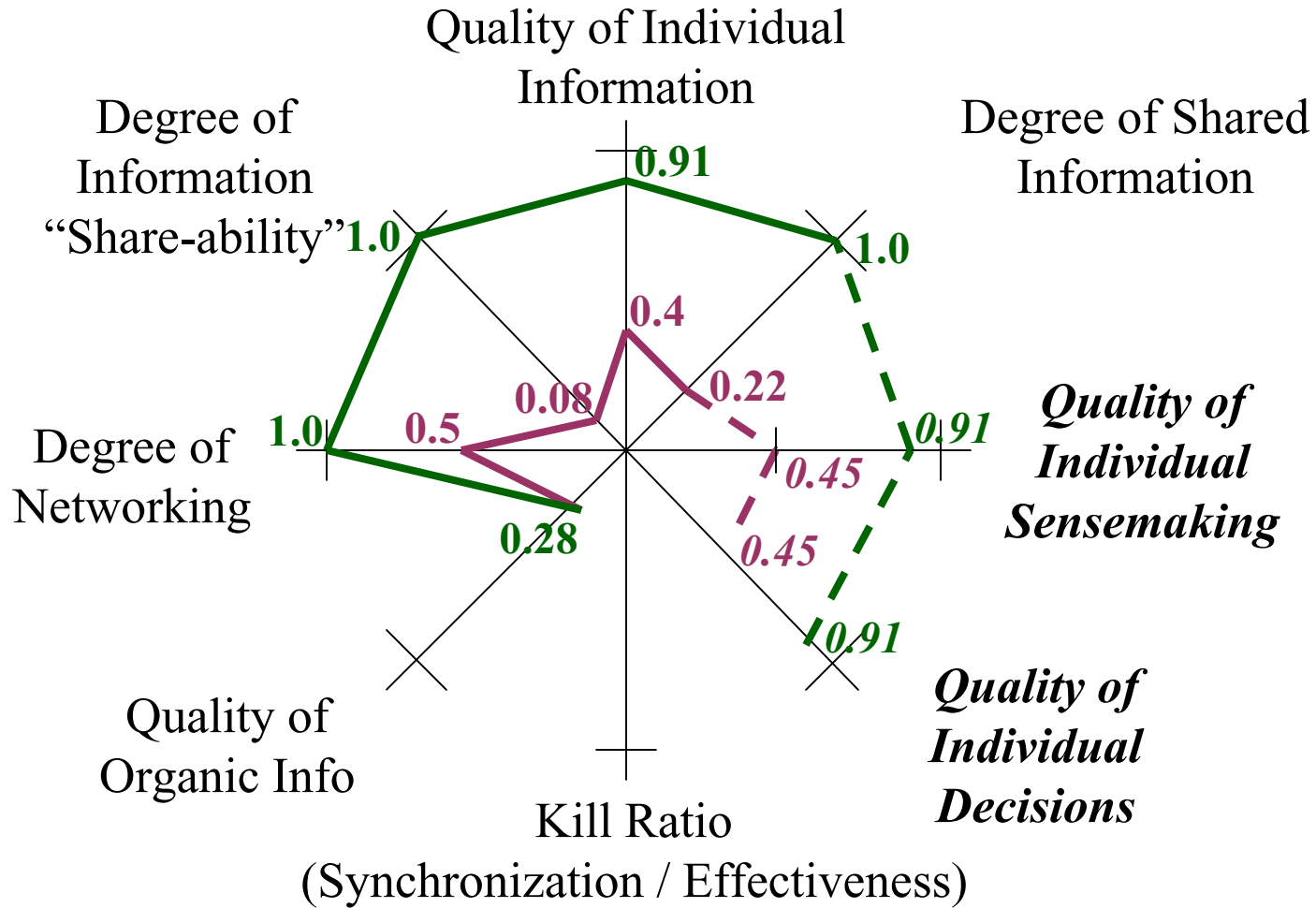
Quality of Individual Sensemaking and Decision Making: Timeliness





Comparing MCPs Using Summary Metrics

Quality of Individual Sensemaking and Decisions (Notional)

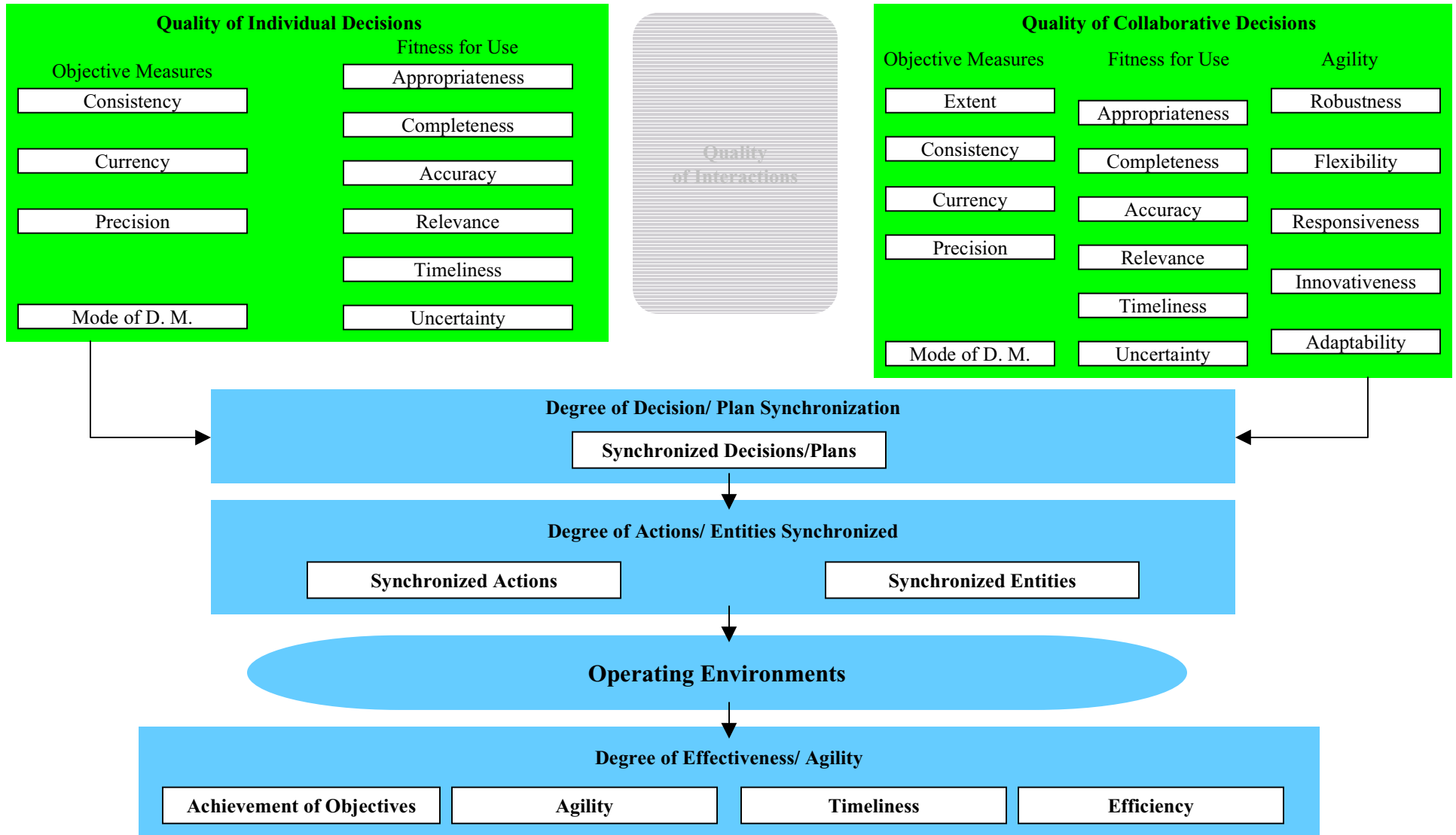


Overall average over information quality dimensions and package members



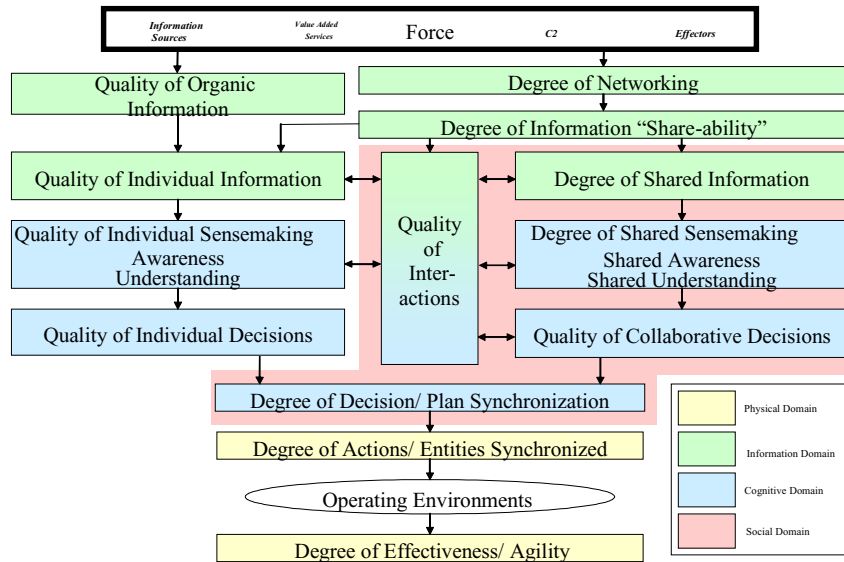
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Influence of Individual and Collaborative Decisions on Synchronization and Effectiveness / Agility



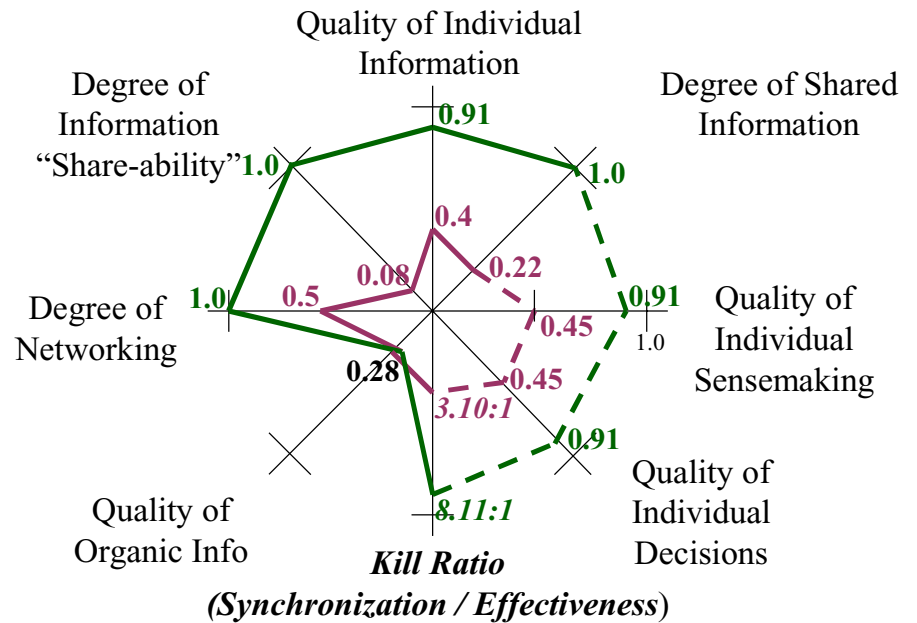


Major Products



NCW Conceptual Framework

Air-to-Air Case Study





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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)



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Degree of Networking: Net Ready Nodes

Nodes that are capable of sharing information and collaborating with others

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



Degree of Networking: Net Ready Nodes

Nodes that are capable of sharing information and collaborating with others

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