C2 Theory
Overview, Recent Developments, and Way Forward

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Dr. David S. Alberts
Institute for Defense Analyses

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Agenda

• What is “C2 Theory”?
• Evolution of Theory – 1995 to 2016
• Battlefield of 2050 and the Implications for C2
• Frontiers of C2 Research
What is “C2 Theory”? 

- C2 Theory focuses on answering a set of ‘strategic-level’ questions in the context of military and civil-military missions and the environments in which these missions take place, including:
  - How do C2 concepts, approaches, and capabilities need to evolve to meet the challenges posed by complex enterprises undertaking complex missions (Complex Endeavors)?
  - What will S&T trends and the capabilities they enable affect the ‘battlefields’ of the future and our ability to exercise C2?
  - How can we more effectively and efficiently accomplish the functions associated with C2?
  - What is the C2 value chain and how can it be observed and measured?
C2 Theory builds upon, applies, and integrates theories and evidence from disparate disciplines

- organizational design
- perception
- network science
- military history
- communication
- management
- autonomy
- team building
- cybersecurity
- leadership
- sociology
- collaboration
- agility
- control theory
- culture
- decision making
- knowledge management
- psychology
- Information science
- simulation
- robotics
- complex systems
- game theory
- risk management
- and many more
Three Perspectives on C2

Commander (an individual)

- Intent
- Roles
- Relationships
- Information flows
- ROE
- Resources

Command Approach

Control Approach

Quality of Information

Information Collection & Dissemination

Direct Effects
Consequences

State (t), State (t+ Δt)

Individual Characteristics & Behaviours

Team Characteristics

Individual Awareness, Understanding, & Knowledge

Shared Awareness, Understanding, & Knowledge

individual

Decision making

collective

Quality of Decisions

Actions

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Three Perspectives on C2

Team – Organization - Collective

Command Approach

Individual Characteristics & Behaviours

Team Characteristics

State (t), State (t + Δt)

Quality of Decisions

Actions

Control Approach

Individual Awareness, Understanding, & Knowledge

Shared Awareness, Understanding, & Knowledge

Information Collection & Dissemination

Direct Effects

Consequences

- Intent
- Roles
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- ROE
- Resources

Individual

Decision making

collective

Quality of Information

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Three Perspectives on C2

Approach to Command and Control - Creates the conditions that shape how C2 functions are carried out on the battlefield and determine C2 effectiveness

- Intent
- Roles
- Relationships
- Information flows
- ROE
- Resources

Command Approach

Control Approach

Sensemaking

Individual Characteristics & Behaviours

Individual Awareness, Understanding, & Knowledge

Team Characteristics

Shared Awareness, Understanding, & Knowledge

individual

Decision making

collective

Quality of Decisions

Actions

Information Collection & Dissemination

Direct Effects Consequences

State (t), State (t+ Δt)

Quality of Information

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Evolution of C2 Theory 1995-2016

• Circa 1995

• Cooperative Engagement

• Network Centric Warfare (now NEC) and Maturity Model

• C2 Approach Space

• C2 Agility

• C2 of Composite Networks
Shifting Focus and Emphasis
from C2 to C3 to C3I to C4ISR and Back to C2
What is Information War?

Command Arrangements for Peace Operations

Operations Other Than War

Unintended Consequences of Information Age Technologies

Defensive Information Warfare

Dominant Battlespace Knowledge
Cooperative Engagement

• Cooperative Engagement Capability (CEC) a real-time sensor netting system that enables high quality situational awareness and integrated fire control capability

• Broke the sensor to shooter stovepipe

• Developed a shared (common) operating picture

• Improved targeting precision by sensor data fusion

• Extended the engagement envelopes of weapons

focus on improvements to a set of kill chains
Origins of Network Centric Warfare?

NCW is an approach to operations that embraces Information Age concepts and is enabled by Information Age technologies.

What would we change if we had total situation awareness?

C4I for the Warrior

Disruptive Innovation

Spawning of Processing in Real Time Systems

Co-evolution of Mission Capability Packages

Common Operational Picture

Virtual Organizations

Sensor to Shooter

Cooperative Engagement Capability

Primordial Soup of NCW

C2 as a force multiplier
What is Network Centric Warfare?

• NCW = an Information Age Transformation

• A new way of thinking about
  - how we accomplish our missions
  - how we organize and interrelate to one another
  - how we acquire and field the systems that support us

• NCW is not all about technology or a collection of systems; rather NCW is enabled by an increasingly capable infostructure

• NCW can be successfully practiced at various levels of maturity under difference circumstances
Tenets

A robustly networked force improves Information Sharing

Information Sharing and Collaboration enhances Quality of Information and Shared Situational Awareness

Shared situational awareness enables Collaboration and Self-synchronization

These, in turn, dramatically increase mission effectiveness.
The “W” in NCW was deliberate - to emphasize the point that NCW was not about information technology and communications networks but rather about warfare.

The change to Network Centric Operations (NCO) was intended to counter the view that network-centric concepts and capabilities were only applicable to high-end combat rather than to the full mission spectrum including non-kinetic missions.
“This publication will assist the joint warfighting community in taking the necessary steps to pursue the change associated with the ongoing revolution in military affairs.

The emerging evidence for network-centric warfare as the intellectual basis for Joint Vision 2010.”

CJCS
Evolution of Terminology
(network-centric v. network-enabled)

• The term “network-centric” was chosen as a direct contrast to the then existing “platform-centric” mindset
• The network-centric proposition was that, for a given investment, one could generate more value by “networking the force” than by adding platforms
• Thus, it was networking (of entities) that is central to military operations, not individual platforms
• Many misunderstood the term network-centric and focused on the technology as an end unto itself
• The adoption of the term “network enabled” was an attempt to make sure that the emphasis remained on the operations that were enabled, not on the technical networks
Conditions for Self-Synchronization

- Common Perceptual Filters
- High Quality Information
  - Information Availability
- High Quality Situation Awareness
  - Collaborative C2 Processes
  - Competence
  - Empowering Leadership
  - Congruent Command Intent
  - Trust
    - Informational
    - Organizational
  - Effective Self-Synchronization

- High Quality Shared Situation Awareness
- Shared Knowledge & Experience
  - Military Education
    - Training
    - Exercises
    - Operations
Network-Enabled Value Chain
involves multiple domains

Information Domain
- Robustly Networked Force
- Information Sharing
- Quality of Information

Cognitive Domain
- Shared Situational Awareness
- Collaboration

Physical Domain
- Self-Synchronization
- Mission Effectiveness

Social Domain

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Co-evolution

New & Co-evolved
- concepts of operations
- organization (roles, relationships)
- processes
The Magic of NEC

Information Domain

- Robustly Networked Force
- Information Sharing
- Quality of Information

Cognitive Domain

- Shared Situational Awareness
- Collaboration
- Self-Synchronization

Physical Domain

- Mission Effectiveness

This is where the magic of NEC happens
The magic of NEC

The magic is new network-enabled approaches to C2

This is where the magic of NEC happens
Network Enabled C$^2$
(NEC$^2$)

• Information flows must be freed from the chain of command

• Patterns of Interaction must be less constrained

• Roles and responsibilities need to change appropriately

• One Size Does Not Fit All
Network Enabled C²
(NEC²)

• Information flows must be freed from the chain of command
• Patterns of Interaction must be less constrained
• Roles and responsibilities need to change appropriately
• One Size Does Not Fit All

We needed a new construct to help us think about C2 Approaches that helps us to compare and contrast their differences.
There are a great many possible approaches to accomplishing the functions that we associate with Command and Control.

Developing the “option space” for Command and Control requires that major differences between possible approaches are identified.

These differences are reflected in the dimensions of the C2 Approach Space (options available)

- Allocation of Decision Rights (ADR)
- Patterns of Interaction (PoI)
- Distribution of Information (DoI)

A region in the C2 approach Space represents a specific approach to C2
NCW Migration and the $C^2$ Approach Space

**Situational Awareness**

Command and Control Approach

1. Traditional Collaboration
2. Self-synch
3. Distribution of Information
4. Allocation of Decision rights

Patterns of Interaction

Shared Awareness

Info Sharing

Organic sources

Traditional Military $C^2$
Necessary $C^2$-related Changes

- Access to information to ensure that those who need it can get it
- Authority and processes that are consistent with who knows what and when they know it
- Doctrine and tactics to exploit information advantage
- Systems requirements to provide needed capabilities
- Policies to enable and encourage wide-spread sharing of information and collaboration
C2 Agility

- There are *many ways* to accomplish the functions associated with Command and Control.
- No one approach to accomplishing the functions associated with command and control fits all missions or situations whether for a single entity or a collection of independent entities (a collective).
- The most appropriate approach will be a function of the endeavor and the prevailing circumstances.
- Therefore, Entities (and Collectives) will need to be able to employ more than one approach.
- C2 Agility is the ability to appropriately move around in the C2 Approach Space in response to changing missions and circumstances.
- Agile C2 systems and processes are required for C2 Agility and to make specific approaches to C2 more agile.
This is a most appropriate C2 Approach for this particular set of circumstances
When circumstances change, a different approach might be more appropriate.

*C2 Agility involves recognizing the significant of a change in circumstances, understanding the most appropriate C2 Approach for the circumstance and being able to transition to this approach.*
Measuring C2 Agility

• The degree of agility possessed by an entity is a function of its ability to successful operate over an appropriate set of circumstances (Endeavor Space)

• A scalar measure of agility is defined as the area of the region in the Endeavor Space where an entity can successfully operate

\[
\text{Agility} = \frac{\text{Area of } \bullet}{\text{Area of } \bigcirc}
\]
C2 Agility

- C2 Agility = $f \,(\text{C2 Approach Agility, C2 Maneuver Agility})$

**C2 Approach Agility** is the area of the region in the Endeavor Space where an entity can operate successfully by employing a given approach to C2.

**C2 Maneuver Agility** is the ability to recognize the C2 approach appropriate for the circumstances and transition to this approach in a timely manner. It is a function of the set of C2 Approaches available to the entity.
C2 Agility Hypotheses

H1: Each C2 Approach is located in a distinct region of the C2 Approach Space

H2: No one approach is always the most appropriate
C2 Agility Hypotheses

H3: More network-enabled approaches are more appropriate for Complex Endeavors; while less network-enabled approaches are more appropriate for less complex missions/circumstances
H4: More network-enabled approaches are more agile (have greater C2 Approach Agility)
H5: The dimensions of the C2 approach Space are positively correlated with agility
C2 Agility Hypotheses

H6: More network-enabled approaches are better able to maintain their intended positions in the C2 Approach Space

H7: On-diagonal (balanced) approaches are more agile

H8: Increasing C2 Maneuver Agility increases agility
H9: More mature C2 capability is more agile than the C2 Approach Agility of the most network-enabled approach available

H10: Self monitoring is required for C2 Maneuver Agility

H11: The six enablers of agility are collectively exhaustive and thus all instances of observed agility can be traced to one or more of these enablers

H12: Each of these enablers is positively correlated with agility
Creating an Endeavour Space

• The Endeavor Spaces were populated by combining all possible values of multiple variables, each one corresponding to an aspect of the situation

• Heat maps show the progressive degree of challenge of the Endeavour Spaces
  – Darker shades of orange represent most challenging circumstances
  – Values were normalized across the experiments
Comparative Agility Map

with varying conditions of signal to noise
and with varying requirements
for shared situation awareness and response time

Source: Alberts, D.S. The Agility Imperative, 2010 Part V: Agility Experiments
C2 Agility dynamically adjusts who and how decisions are made, how we work together and how information is shared. Agility is required because the world is dynamic, conditions and circumstances change, missions maybe unfamiliar, and what is currently working may not work well or continue to work well. C2 Agility Theory informs and helps institutionalize best practices.
Agenda

• What is “C2 Theory”?

• Evolution of Theory – 1995 to 2016

• Battle Field of 2050 and Implications for C2

• Implications for C2 Research
Battlefield of 2050

Army Research Office (ARO) and Army Research Laboratory (ARL) Workshop

• Fewer human warriors, but with superhuman capabilities, both cognitively and physically enhanced
• Ubiquitous intelligent systems with varying degrees of autonomy
• Networked by the Military Internet of Things (IoT)
• Battle for the information domain
  – cover, concealment, and cloaking v persistent surveillance
  – deception and misinformation v. big data analysis
• Battle for cyberspace dominance

The entity that can effectively command and control this heterogeneous collection of battlefield assets and capabilities will have a decisive advantage
Battlefield of 2050

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The entity that can effectively command and control this heterogeneous collection of battlefield assets and capabilities will have a decisive advantage
Battlefield of 2050

Army Research Office (ARO) and Army Research Laboratory (ARL) Workshop means

• a target rich environment that requires prioritization & standoff capabilities to avoid targeting or fleeting targets and increased surprise

• Battle for the information domain
  – cover, concealment, and cloaking v persistent surveillance
  – deception and misinformation v. big data analysis

• Battle for cyberspace dominance

The entity that can effectively command and control this heterogeneous collection of battlefield assets and capabilities will have a decisive advantage
Battlefield of 2050

Army Research Office (ARO) and Army Research Laboratory (ARL) Workshop

- Fewer human warriors, but with superhuman capabilities, means
  - persistent attacks that will require effective cybersecurity defenses and adaptive networks to minimize
  - degraded network connectivity, network performance and data quality
- Battle for cyberspace dominance

The entity that can effectively command and control this heterogeneous collection of battlefield assets and capabilities will have a decisive advantage
C2 Battlefield 2050 Challenge

Command and Control of a heterogeneous collection of networked battlefield assets with varying degrees of intelligence, experience, autonomy, and agility in a dynamic, unpredictable, and contested environment.
A Composite Network is a heterogeneous collection of intelligent interdependent networks

- Social networks consisting of humans, robots and agents that can be influenced / controlled
- Information networks that respond to or generate requests for information and disseminate information
- Communication networks that provide connectivity, routing and related services for both the social and information networks

Social, Information, and Communication Networks can include agents that make them self-aware with the ability to sense the state of the network and modify its behaviors accordingly
Composite Network Model Overview

Design

Behaviors

Performance

Value

C2/ Social Network

Design

Capabilities

network performance map

Information Network

Design

Capabilities

network performance map

Communication Network

Design

Capabilities

network performance map

Endeavor Space

Probability of Success

given mission/circumstances

Enterprise Agility
Integrated Design and C2

Design / Capabilities Space

C² Approach Process

QoC² Performance Map

QoC²

QoI Performance Map

QoI

QoC Performance Map

QoC

Probability of Mission Success given location in ES

Enterprise Agility
C2 Approaches for Composite Networks

- Social / Cognitive Network
  Commanders can maneuver in the C2 Approach Space within organizational design constraints

- Information and Communications Networks
  Commanders can tune a set of the specific network design parameters values within network design constraints

Effective C2 of Composite Networks requires a holistic approach
Frontiers of C2 Agility Research

• Composite Networks
  – Integrated Design, Cyber Security, Automation and autonomy
  – Monitoring and agile behaviors
  – Integrated C2

• C2 Agility
  – Measurement
  – Visualization for commanders
  – Endeavor Space

• Coalition / Collective C2
  – Harmonizing entity C2 Approaches with the Collective
Thoughts?
Questions?
Backup Slides
Traditional Military C$^2$
Assumptions

• Someone is recognized as “in charge”

• A single chain of command exists

• Patterns of interaction are defined by doctrine

• Information distribution follows the chain of command
NCW and $C^2$

NCO
Is NCW an existential threat to traditional $C^2$?
NEC
Approaches in the C2 Approach Space

H1: Each of the NATO C2 Maturity Model approaches is located in a distinct region of the C2 Approach Space
Combined results show that C2 approaches are located in distinct regions of the C2 Approach Space.
No ‘One Size’ Fits All

H2: No one approach to C2 is always the most appropriate

H3: More network-enabled approaches to C2 are more appropriate for more challenging circumstances; however, less network-enabled C2 approaches to C2 are more appropriate for some circumstances
More Network-Enabled = More Agility

H4: More network-enabled approaches to C2 are more agile

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Cognitive Complexity</th>
<th>Conflicted</th>
<th>De-Conflicted</th>
<th>Coordinated</th>
<th>Collaborative</th>
<th>Edge</th>
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<tbody>
<tr>
<td>Complex Endeavor</td>
<td>High</td>
<td>Low</td>
<td>Med</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Collaboration</td>
<td>High</td>
<td>Low</td>
<td>Med</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Coordination</td>
<td>High</td>
<td>Low</td>
<td>Med</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Industrial Age</td>
<td>High</td>
<td>Low</td>
<td>Med</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

- Darker shades of teal correspond to higher levels of mission success (1), lighter ones to failure (0)
- Blank squares represent non-simulated cases

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More Network-Enabled = More Agility

De-Conflicted was successful in 27 out of 54 circumstances
Agility Score (IMAGE, De-Conflicted) = 27/54 = 0.50

- Darker shades of teal correspond to higher levels of mission success (1.0), lighter ones to failure (0.0)
- Blank squares represent non-simulated cases
Results suggest that Agility accelerates as C2 approaches become more network-enabled.

The relation between C2 Approach and Agility Score is quadratic ($R^2 = 0.99$).

![Graph showing the quadratic relationship between C2 Approach and Agility Score with $R^2 = 0.9937$.]
H5: The dimensions of the C2 Approach Space are positively correlated with agility

- Individually: Agility Score is strongly correlated to each dimension of the C2 Approach Space
- Collectively (multiple regression):

Agility Score = 0.030 + 0.460 x Allocation of decision rights
− 0.269 x Patterns of interaction
+ 0.274 x Distribution of information

\[ R^2_{ADR} = 0.965 \]
\[ R^2_{Pol} = 0.858 \]
\[ R^2_{DoI} = 0.983 \]
Location Variations in C2 Approach Space

H6: More network-enabled C2 approaches are better able to maintain their position in the C2 Approach Space

- Only patterns of interaction and distribution of information were affected by circumstances

- The deviation was measured by the spreading, calculated from the area occupied by all circumstances
H6: More network-enabled C2 approaches are better able to maintain their position in the C2 Approach Space

Location Variations in C2 Approach Space
H7: On-diagonal (balanced) approaches to C2 are more agile

<table>
<thead>
<tr>
<th>C2 Approach</th>
<th>On-Diagonal Group</th>
<th>Off-Diagonal Group</th>
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</thead>
<tbody>
<tr>
<td>Average % Maximum Effectiveness</td>
<td>82%</td>
<td>36%</td>
</tr>
<tr>
<td>Average Distance from Diagonal</td>
<td>0.02</td>
<td>0.09</td>
</tr>
</tbody>
</table>
H9: More mature C2 capability is more agile than the most agile C2 Approach that can be adopted

<table>
<thead>
<tr>
<th>C2 Maturity Levels</th>
<th>Contents of C2 Toolkit</th>
<th>C2 Approach Decision Requirement</th>
<th>Transition Requirements</th>
<th>Region of the Endeavor Space where a collective is successful</th>
</tr>
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<tbody>
<tr>
<td>Level 5</td>
<td>Edge C2</td>
<td>Emergent</td>
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<td></td>
<td>Collaborative C2</td>
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<tr>
<td></td>
<td>Coordinated C2</td>
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<td>Level 4</td>
<td>Collaborative C2</td>
<td>Recognize 3 situations</td>
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<td></td>
<td>Coordinated C2</td>
<td>and match to appropriate C2</td>
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<td></td>
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<tr>
<td></td>
<td>De-Conflicted C2</td>
<td>approach</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 3</td>
<td>Coordinated C2</td>
<td>Recognize 2 situations</td>
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<td>and match to appropriate C2</td>
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<td>Level 1</td>
<td>Conflicted C2</td>
<td>N/A</td>
<td></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
</tbody>
</table>

Adapted from the Alberts, D.S. (2011). Agility Advantage, CCRP
H9: More mature C2 capability is more agile than the most agile C2 Approach that can be adopted
Experimental results suggest more an imbricated model than a complementary one.