Operationalizing and Improving C2 Agility: Lessons from Experimentation

David S. Alberts
dalberts@ida.org

Marco Manso
marco@marcomanso.com
Agenda

• Paper’s Objectives
• From Theory to Practice: Cornerstones
• C2 Agility Experiments
• Results of Experiments
• Conclusions
Objectives

- Identify what it takes to “Operationalize C2 Agility”
- Determine if we are ready to improve the practice
- Provide a “proof of concept” by designing and conducting experiments
- Identify lessons learned from experiments regarding improving Agility C2
Operationalizing C2 Agility

- Operationalize = move from a concept to a theory to a practice
- “Excellence is not an act; but a habit” *Aristotle*
- Foundation to build practice upon

- Theory
- Metrics
- Measurement
- Milestones

Operationalizing C2 Agility makes C2 Agility “a habit”
Theory: Conceptual Foundation

- **C2 Approach Space**

- **C2 Conceptual Reference Model**
  Reference: NATO NEC C2 Maturity Model (N2C2M2)

- **NATO NEC C2 Maturity Model (N2C2M2)**

- **C2 Maturity Levels**
  Reference: NATO NEC C2 Maturity Model (2010)

- **Agile C2**

- **Agility Metric and Measurement Process**
  Reference: The Agility Advantage (2011)
What is Agility?

Agility is the capability to successfully effect, cope with and/or exploit changes in circumstances.
What is Agility?

Agility is the capability to successfully effect, cope with and/or exploit changes in circumstances.

- The concept of Agility does not apply to a stable situation.
- External changes (e.g., regime change, permissive to hostile).
- Changes to self (e.g., a new coalition partner, loss of capability).
What is Agility?

Agility is the capability to successfully effect, cope with and/or exploit changes in circumstances within acceptable bounds of performance (e.g. effectiveness, efficiency, risk).
What is Agility?

Agility is the capability to successfully effect, cope with and/or exploit changes in circumstances to respond to an event that would otherwise have adverse consequences.
What is Agility?

Agility is the capability to successfully effect, cope with and/or exploit changes in circumstances.

- take advantage of an opportunity to improve effectiveness and/or efficiency
- or reduce risk
What is Agility?

Agility is the capability to successfully effect, cope with and/or exploit changes in circumstances.

take actions to effect change or to prevent changes that might otherwise occur
Components of Agility

• Responsiveness
• Versatility (previously referred as robustness)
• Flexibility
• Resilience
• Adaptiveness
• Innovativeness

The contributions of these components to agility are not additive
There are many ways (i.e., approaches) to accomplish the functions associated with Command and Control.

No single approach to C2 (i.e., C2 approach) 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.

HOWEVER: What C2 Approaches? What advantages?
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.

- Centralized v. Decentralized
- Fixed Vertical Stovepipes v. Dynamic Task Organized
- Limited information dissemination (need to know) v. broad dissemination (need to share)

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

- Allocation of Decision Rights (within an entity or to the collective)
- Patterns of Interaction
- Distribution of Information
C2 Approach Space

- **Patterns of Interaction**
  - unconstrained
  - tightly constrained

- **Distribution of Information**
  - none
  - broad

- **Allocation of Decision Rights**
  - none
  - broad
N2C2M2 C2 Approaches

Collective C2 Approaches
- Edge C2
- Collaborative C2
- Coordinated C2
- De-Conflicted C2
- Conflicted C2

Source: NATO NEC C2 Maturity Model
N2C2M2 Hypotheses

• For a complex endeavor, more network-enabled C2 approaches are **more effective** than less network-enabled C2 approaches.

• For a given level of effectiveness, more network-enabled C2 approaches are **more efficient** than less network-enabled C2 approaches.

• More network-enabled C2 approaches have **more agility** than less network-enabled C2 approaches.

More network-enabled C2 approaches exhibit increased/better levels of:

• Quality of Individual and Shared Information;

• Quality of Individual and Shared Awareness and Understanding;

• **Self-Synchronization**;

Than: less network-enabled C2 approaches.

Adapted from (Manso 2012)
The N2C2M2 Agility hypothesis merits serious exploration because the increased complexity and the associated increases in uncertainty and unpredictability and, therefore, risk challenges key traditional C2 assumptions
Agenda

• Paper’s Objectives
• From Theory to Practice: Cornerstones
• C2 Agility Experiments
• Experimental Results
• Conclusions
Purpose of Experiments

- Experiments constitute a “proof of concept” that we have the foundation in place to begin to operationalize C2 Agility. They show we can:
  - Characterize and represent different approaches
  - Locate them in the C2 Approach Space
  - Define an Endeavor Space (required by Agility Theory)
  - Observe agility-related variables
  - Calculate Agility-related metrics
  - Compare the agility of two C2 Approaches
  - Identify proximally cause(s) of agility or a lack of agility
• Command and Control Research Program (CCRP) sponsored the design and development of the ELICIT platform to facilitate experimentation focused on information, cognitive, and social domain phenomena

• ELICIT is a web-accessible experimentation environment supported by software tools and instructions / procedures

• abELICIT is an agent-based version of the ELICIT platform
ELICIT Scenarios

• The goal of each set of participants is to build situational awareness and identify the who, what, when, and where of a pending attack
  – Factoids are periodically distributed to participants; each participant receives a small subset of the available factoids
  – No one is given sufficient information to solve without receiving information from others
  – Participants can share factoids directly with each other, post factoids to websites, and by “keyword directed” queries
  – Participants build awareness and shared awareness by gathering and cognitively processing factoids

• The receiving, sharing, posting, and seeking of factoids and the nature of the interactions between and among participants can be constrained
• Participants can be “organized” and motivated in any number of ways
• Various stresses can applied (e.g. communications delays and losses)
• Software-Agents are used instead of humans
Controllable Variables

Network Characteristics & Performance

Info Sharing & Collaborative Behaviors

Task Difficulty

Quality of Information Sources

Culture

Controllable in Human Trials
Only in abELICIT
In Both

C2 Approach

Shared Information

Shared Awareness

Shared Understanding

Quality of Information

Quality of Awareness

Quality of Understanding

Task Performance

Measures of Merit

Individual & Team Characteristics
Experimentation Campaign

• **Objective**: observe the agility of a range of C2 Approaches options.

• **Methodology**
  - A set of C2 Approach Options were defined and instantiated
  - Measures of Effectiveness, Timeliness, and Efficiency (MoMs) were defined (dimensions “acceptable” mission performance)
  - An Endeavor Space was created composed of:
    - A set of mission challenges related to the timeliness of information availability
    - A range of Agent capabilities
    - A range of Infostructure conditions
    - A range of levels of organizational disruption
  - abELICIT runs were made that spanned Endeavor Space for each of the C2 Approach Options
Methodology

Set the Baseline

Conduct ELICIT Runs in *normal* circumstances

RESULTS (task performance, …)

Change in Circumstances

Conduct ELICIT Runs in *changed* circumstances:
- Information availability
- Agents performance
- Infrastructure degrad.
- Organization disrupt.

RESULTS (task performance, …)

Measure Agility

Calculate Agility and related measurements

**Absolute agility** (percentage of area in endeavor space in which an entity can operate successfully)
# Experimentation Campaign

- **Manipulations**

<table>
<thead>
<tr>
<th>Manipulations</th>
<th>Description</th>
<th>Agility component to observe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Key Information Availability</strong></td>
<td>The point at which key information is made available is varied. When information is provided later there is less time to accomplish the task.</td>
<td>Versatility (over problem difficulty) Responsiveness</td>
</tr>
<tr>
<td><strong>Agent Performance</strong></td>
<td>Three levels of agent performance were simulated to include: ‘lower performing’, ‘normal performing’ and ‘high performing’.</td>
<td>Versatility (of organization) Responsiveness</td>
</tr>
<tr>
<td><strong>Infrastructure Degradation</strong></td>
<td>Infrastructure performance was degraded by removing links between nodes and websites.</td>
<td>Resilience (of infrastructure) Responsiveness</td>
</tr>
<tr>
<td><strong>Organization Disruption</strong></td>
<td>The organization will be disrupted by eliminating nodes (i.e., individuals).</td>
<td>Resilience (of organization) Responsiveness</td>
</tr>
</tbody>
</table>
Experimentation Campaign

- C2 Approaches Instantiated
Experimentation Campaign

- C2 Approaches Instantiated (Position in the C2 Approach Space)
Experimentation Campaign

- **C2 Approaches Instantiated (BASELINE Results)**

<table>
<thead>
<tr>
<th>C2 Approach</th>
<th>Average Correctness</th>
<th>Maximum Timeliness</th>
<th>Effectiveness*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinated C2</td>
<td>0.06</td>
<td>0.17</td>
<td>1</td>
</tr>
<tr>
<td>CTC-TL Collaborative C2</td>
<td>0.29</td>
<td>0.20</td>
<td>1</td>
</tr>
<tr>
<td>Collaborative C2</td>
<td>0.35</td>
<td>0.40</td>
<td>1</td>
</tr>
<tr>
<td>Edge C2</td>
<td>1.00</td>
<td>0.20</td>
<td>1</td>
</tr>
</tbody>
</table>

* C2 Approach Specific
• Paper’s Objectives
• From Theory to Practice: Cornerstones
• C2 Agility Experiments
• Results of Experiments
• Conclusions
Results of Experiments

- Key Information Availability – Agility measurements

More network-enabled C2 Approaches are more Agile than less network-enabled approaches.

<table>
<thead>
<tr>
<th>C2 Approach</th>
<th>Absolute Agility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinated C2</td>
<td>0.05</td>
</tr>
<tr>
<td>CTC-TL Collaborative C2</td>
<td>0.14</td>
</tr>
<tr>
<td>Collaborative C2</td>
<td>0.2</td>
</tr>
<tr>
<td>Edge C2</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Results of Experiments

• **Impact of Agents Performance – Agility measurements**

Coordinated C2  CTC-TL Collaborative C2  Collaborative C2  Edge C2

More network-enabled C2 Approaches are more Agile than less network-enabled approaches.

<table>
<thead>
<tr>
<th>C2 Approach</th>
<th>Absolute Agility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinated C2</td>
<td>0.02</td>
</tr>
<tr>
<td>CTC-TL Collaborative C2</td>
<td>0.07</td>
</tr>
<tr>
<td>Collaborative C2</td>
<td>0.16</td>
</tr>
<tr>
<td>Edge C2</td>
<td><strong>0.29</strong></td>
</tr>
</tbody>
</table>
Results of Experiments

- Impact of Infostructure Degradation – Performance measurements

<table>
<thead>
<tr>
<th>C2 Approach</th>
<th>Average Correctness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basel.</td>
</tr>
<tr>
<td>Coordinated C2</td>
<td>0.06</td>
</tr>
<tr>
<td>CTC-TL Collaborative C2</td>
<td>0.29</td>
</tr>
<tr>
<td>Collaborative C2</td>
<td>0.35</td>
</tr>
<tr>
<td>Edge C2</td>
<td>1.00</td>
</tr>
</tbody>
</table>
• Impact of Infostructure Degradation – Agility measurements

More network-enabled C2 Approaches are more Agile than less network-enabled approaches.

<table>
<thead>
<tr>
<th>C2 Approach</th>
<th>Absolute Agility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinated C2</td>
<td>0.01</td>
</tr>
<tr>
<td>CTC-TL Collaborative C2</td>
<td>0.04</td>
</tr>
<tr>
<td>Collaborative C2</td>
<td>0.13</td>
</tr>
<tr>
<td>Edge C2</td>
<td>0.32</td>
</tr>
</tbody>
</table>
Results of Experiments

- Impact of Organization Disruption – Performance measurements

<table>
<thead>
<tr>
<th>C2 Approach</th>
<th>Average Correctness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basel.</td>
</tr>
<tr>
<td>Coordinated C2</td>
<td>0.06</td>
</tr>
<tr>
<td>CTC-TL Collaborative C2</td>
<td>0.29</td>
</tr>
<tr>
<td>Collaborative C2</td>
<td>0.35</td>
</tr>
<tr>
<td>Edge C2</td>
<td>1.00</td>
</tr>
</tbody>
</table>

- Baseline performance
- 1 node down performance (mean value)
Results of Experiments

• Impact of Organization Disruption – Agility measurements

More network-enabled C2 Approaches are more Agile than less network-enabled approaches.

<table>
<thead>
<tr>
<th>C2 Approach</th>
<th>Absolute Agility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinated C2</td>
<td>0.01</td>
</tr>
<tr>
<td>CTC-TL Collaborative C2</td>
<td>0.04</td>
</tr>
<tr>
<td>Collaborative C2</td>
<td>0.04</td>
</tr>
<tr>
<td>Edge C2</td>
<td><strong>0.11</strong></td>
</tr>
</tbody>
</table>
Results of Experiments

- **Impact of Organization Disruption – Performance Maps**

### Shared Awareness Performance Map

| Coordinated C2 | CTC-TL Collaborative C2 | Collaborative C2 | Edge C2 |

### Effectiveness Performance Map

| Coordinated C2 | CTC-TL Collaborative C2 | Collaborative C2 | Edge C2 |
Results of Experiments

- Impact of Organization Disruption – Performance Maps

### Shared Awareness Performance Map
- Coordinated C2
- CTC-TL Collaborative C2
- Collaborative C2
- Edge C2

### Effectiveness Performance Map
- Coordinated C2
- CTC-TL Collaborative C2
- Collaborative C2
- Edge C2

<table>
<thead>
<tr>
<th>C2 Approach</th>
<th>Shared Awareness Score</th>
<th>Effectiveness Performance Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinated C2</td>
<td>0.1</td>
<td>0.41</td>
</tr>
<tr>
<td>CTC-TL Collaborative C2</td>
<td>0.31</td>
<td>0.61</td>
</tr>
<tr>
<td>Collaborative C2</td>
<td>0.3</td>
<td>0.59</td>
</tr>
<tr>
<td>Edge C2</td>
<td>0.37</td>
<td>0.44</td>
</tr>
</tbody>
</table>
• Paper’s Objectives
• From Theory to Practice: Cornerstones
• C2 Agility Experiments
• Experimental Results
• Conclusions
Conclusions

• A sufficient foundation is in place to explore C2 Agility using cases studies and experiments
• Ways to measure and visualize Agility (and its enablers) were proposed:
  – Agility Maps
  – Performance Maps
• More networked-enabled approaches to C2 achieved higher levels of shared awareness
• More networked-enabled approaches to C2 were more agile
Way Ahead

- More experimentation is needed, particularly with actual (i.e., real-world) organizations and systems
- Further engage with those in the education and training communities
- Need to improve our simulation capabilities


Thank You!

Operationalizing and Improving C2 Agility: Lessons from Experimentation

David S. Alberts
dalberts@ida.org

Marco Manso
marco@marcomanso.com
Annexes and Additional Material
The NNEC Feasibility Study used the terms *Coherent* and *Disjointed* rather than Transformed and Stand Alone.
<table>
<thead>
<tr>
<th>C2 Approach</th>
<th>Allocation of Decision Rights to the Collective</th>
<th>Patterns of Interaction Among Participating Entities</th>
<th>Distribution of Information (Entity Information Positions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge C2</td>
<td>Not Explicit, Self-Allocated (Emergent, Tailored, and Dynamic)</td>
<td>Unlimited As Required</td>
<td>All Available and Relevant Information Accessible</td>
</tr>
<tr>
<td>Collaborative C2</td>
<td>Collaborative Process and Shared Plan</td>
<td>Significant Broad</td>
<td>Additional Information Across Collaborative Areas/Functions</td>
</tr>
<tr>
<td>Coordinated C2</td>
<td>Coordination Process and Linked Plans</td>
<td>Limited and Focused</td>
<td>Additional Information About Coordinated Areas/Functions</td>
</tr>
<tr>
<td>De-Conflicted C2</td>
<td>Establish Constraints</td>
<td>Very Limited Sharply Focused</td>
<td>Additional Information About Constraints and Seams</td>
</tr>
<tr>
<td>Conflicted C2</td>
<td>None</td>
<td>None</td>
<td>Organic Information</td>
</tr>
</tbody>
</table>
Patterns of Interactions: De-conflicted C2

Entity Cluster

- individual
- interaction
- cluster
Patterns of Interactions: Collaborative C2
Patterns of Interactions: Edge C2
This is a most appropriate C2 Approach for this particular set of circumstances.
C2 Agility

When circumstances change, a different approach might be more appropriate.

C2 Agility involves recognizing the significance of a change in circumstances, understanding the most appropriate C2 Approach for the circumstance and being able to transition to this approach.
# Net-enabled C2 → C2 Maturity → C2 Agility

<table>
<thead>
<tr>
<th>C2 Maturity Levels</th>
<th>Contents of C2 Toolkit</th>
<th>C2 Approach Decision Requirement</th>
<th>Transition Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 5</strong></td>
<td>Edge C2</td>
<td>Emergent</td>
<td><a href="#">Edge C2</a></td>
</tr>
<tr>
<td></td>
<td>Collaborative C2</td>
<td></td>
<td><a href="#">Collaborative C2</a></td>
</tr>
<tr>
<td></td>
<td>Coordinated C2</td>
<td></td>
<td><a href="#">Coordinated C2</a></td>
</tr>
<tr>
<td></td>
<td>De-Conflicted C2</td>
<td></td>
<td><a href="#">De-Conflicted C2</a></td>
</tr>
<tr>
<td><strong>Level 4</strong></td>
<td>Collaborative C2</td>
<td>Recognise 3 situations and match to appropriate C2 approach</td>
<td><a href="#">Collaborative C2</a></td>
</tr>
<tr>
<td></td>
<td>Coordinated C2</td>
<td></td>
<td><a href="#">Coordinated C2</a></td>
</tr>
<tr>
<td></td>
<td>De-Conflicted C2</td>
<td></td>
<td><a href="#">De-Conflicted C2</a></td>
</tr>
<tr>
<td><strong>Level 3</strong></td>
<td>Coordinated C2</td>
<td>Recognise 2 situations and match to appropriate C2 approach</td>
<td><a href="#">Coordinated C2</a></td>
</tr>
<tr>
<td></td>
<td>De-Conflicted C2</td>
<td></td>
<td><a href="#">De-Conflicted C2</a></td>
</tr>
<tr>
<td><strong>Level 2</strong></td>
<td>De-Conflicted C2</td>
<td>N/A</td>
<td>None</td>
</tr>
<tr>
<td><strong>Level 1</strong></td>
<td>Conflicted C2</td>
<td>N/A</td>
<td>None</td>
</tr>
</tbody>
</table>
Agent-based ELICIT (abELICIT)

- Experimentation with live groups of individuals is time consuming and expensive.
- This limits the number of runs that can be made.
- This, in turn, limits the exploration of treatment effects.
- Therefore, the CCRP decided to develop agents that could be used in the place of people.
- abELICIT is an all agent-based simulation model that replaces the people with software agents and uses the ELICIT experimentation platform.
- abELICIT is capable of mixing agents and humans in same experimental trial. [but this capability has only been used to test ELICIT]
Agents look like a human to human participants
Configurable behaviors/personalities using 40+ parameters
Able to perform all human actions
  - Post factoids to website
  - Pull factoids from websites
  - Share factoids with other participants
  - Identify adversary attack
Agents create “mental models” of the situation in the form of truth tables and “judgments” with regard to information sources as a result of factoids received or retrieved and the interactions they have with others