C2 Agility Theory:
Hypotheses and the Empirical Evidence

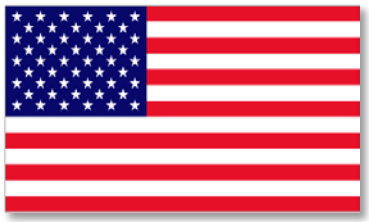
Contributing Nations











Agenda

- Objectives
- Basics of Agility
- C2 Agility
- C2 Agility Hypotheses
- Validation
- Campaign of Experimentation
- Summary of Findings, Conclusions, and Way Ahead

Objectives

- Create awareness of this significant C2 related research area
- Explain the concept of Agility and the basics of C2 Agility Theory and its core hypotheses
- Review the evidence to date

Agenda

- Objectives
- Basics of Agility
- C2 Agility
- C2 Agility Hypotheses
- Validation
- Campaign of Experimentation
- Summary of Findings, Conclusions, and Way Ahead

What is Agility?

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

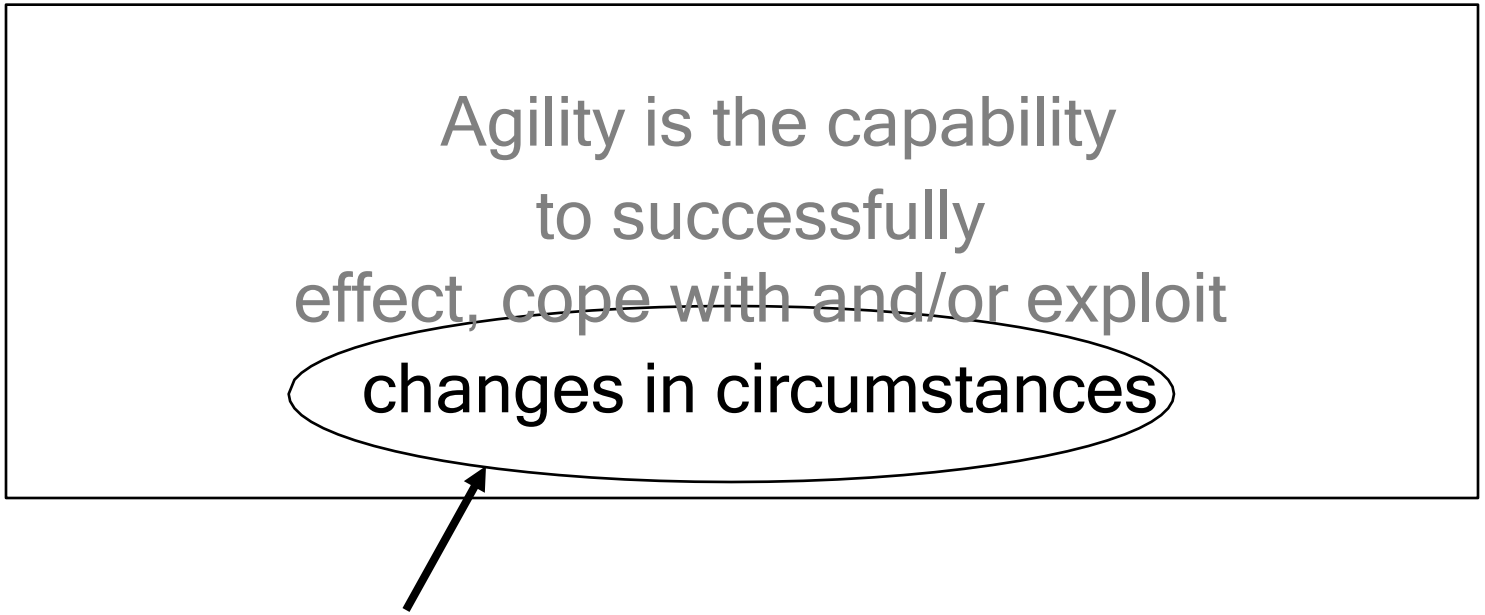
What is Agility?

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

The concept of agility applies to:

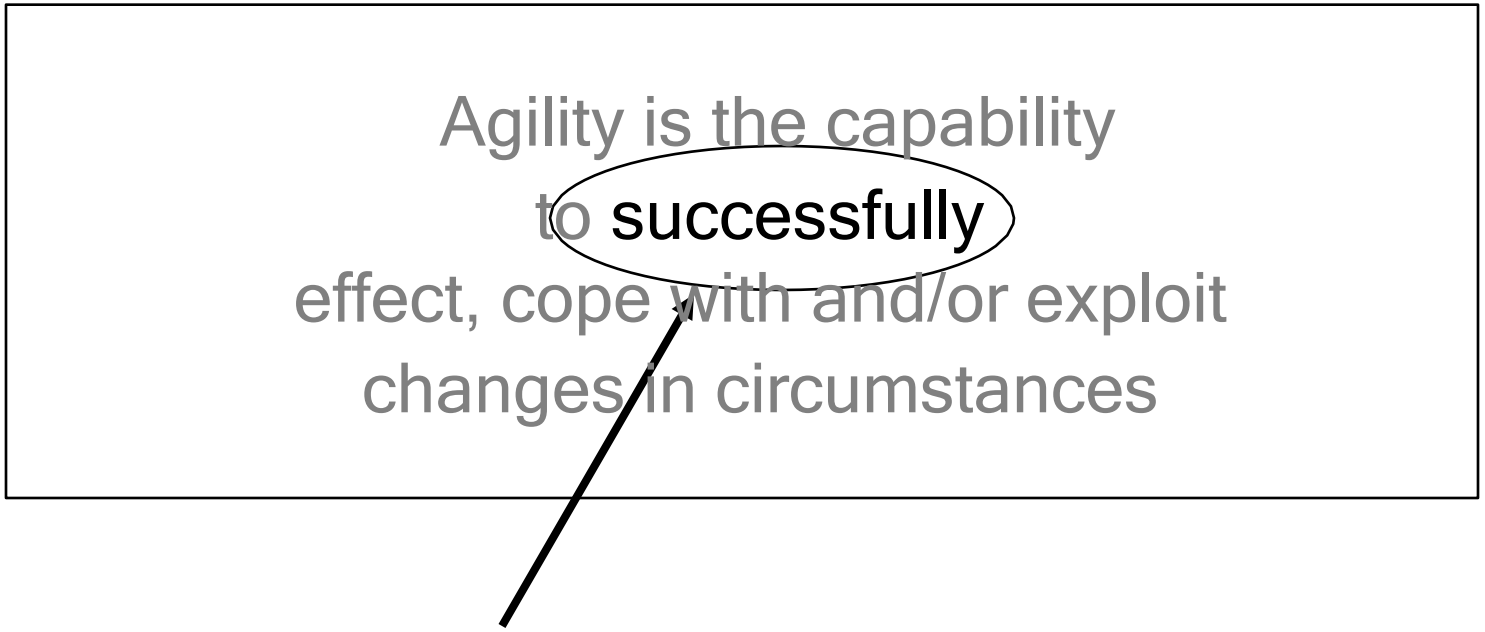
organizations, processes, individuals, systems, equipment, and facilities

What is Agility?



- external changes (e.g. permissive to hostile environment)
- changes to self (e.g. loss of capability such as damage from a cyber attack or need to deploy more intrusive cyber defences)

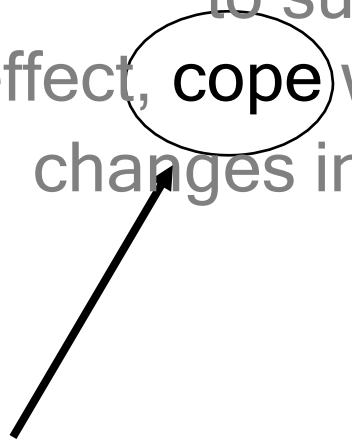
What is Agility?



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



respond to an event that would otherwise have adverse consequences

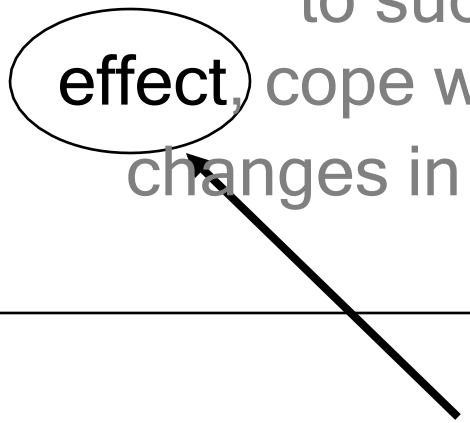
What is Agility?

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

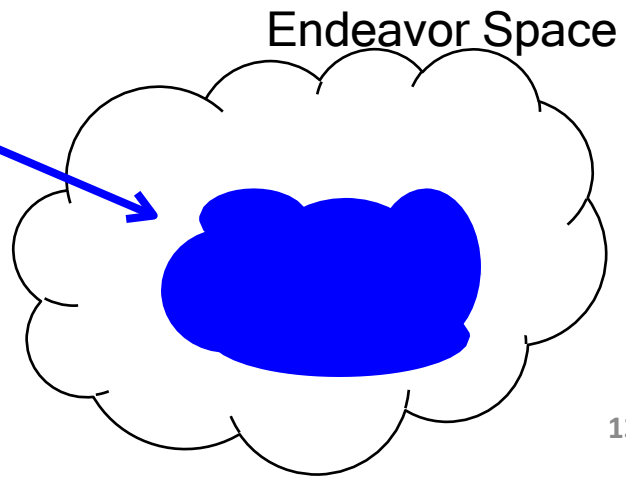


take actions to effect change or to prevent changes that might otherwise occur

Measuring 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

$$\text{Agility} = \frac{\text{Area of } \bullet}{\text{Area of } \circ}$$

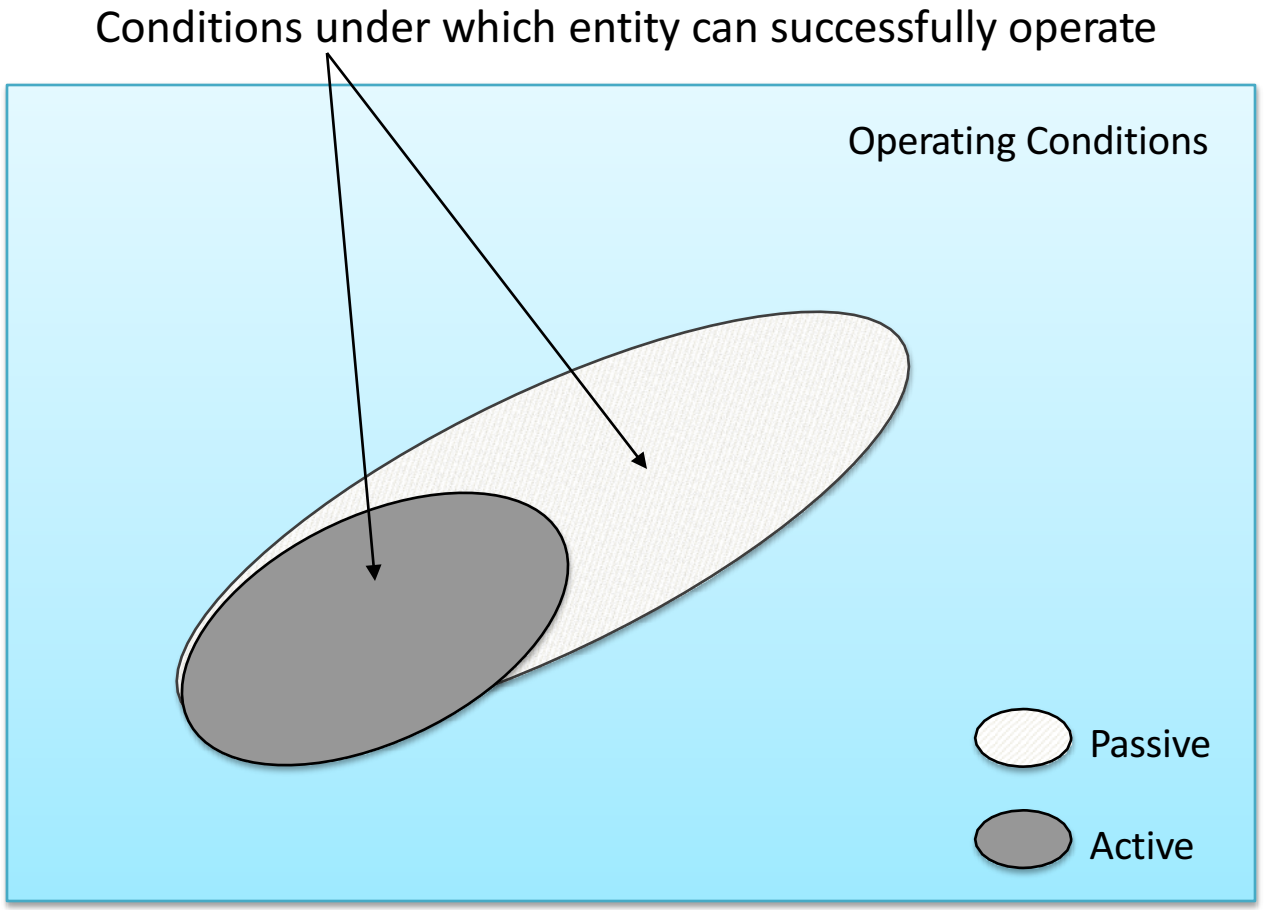


Passive v. Active Agility

- Passive Agility - the set of circumstances, an operating envelope, where an entity can successfully operate without the need for intervention. This may be a result of design or serendipity.

- Active Agility – success depends upon the entity taking some action in anticipation of, or in response to, a change in circumstances in order to prevent a loss of effectiveness that results in failure.

Value-Added of Active Agility



Source: The Agility Advantage

Agenda

- Objectives
- Basics of Agility
- C2 Agility
- C2 Agility Hypotheses
- Validation
- Campaign of Experimentation
- Summary of Findings, Conclusions, and Way Ahead

Need for Agile C2

- 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 appropriately employ more than one approach

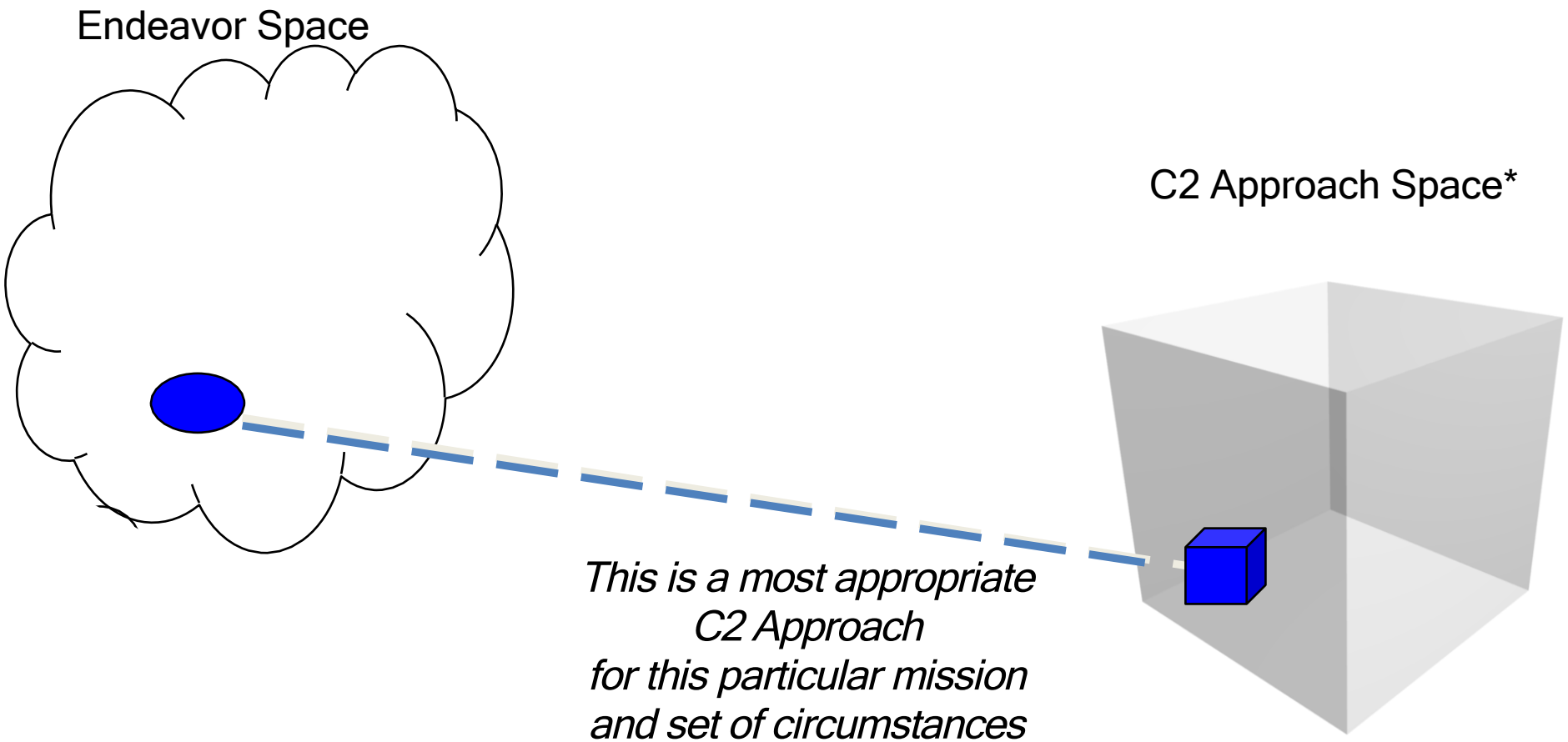
Need for Agile C2

- 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
- 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 appropriately employ more than one approach

All of these are testable hypotheses

C2 Agility

Step 1: Adopt the Appropriate Approach



C2 Approach Space

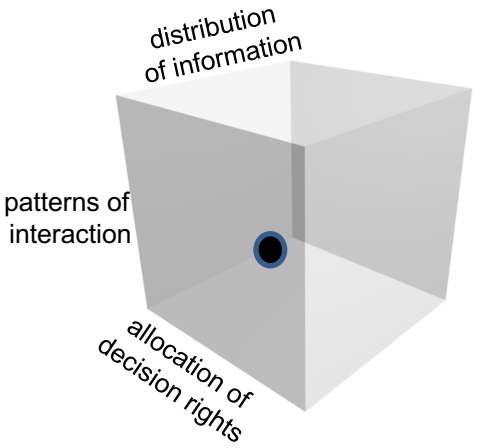
- Experience suggests that C2 approaches differ
  - Centralized vs Decentralized
  - Fixed Vertical Stovepipes vs Dynamic Task Organized
  - Limited information dissemination (need to know) vs broad dissemination (need to share)
- These differences can be visualized using a **C2 Approach Space** that depicts three commander-controllable variables


Allocation of Decision Rights


Patterns of Interaction

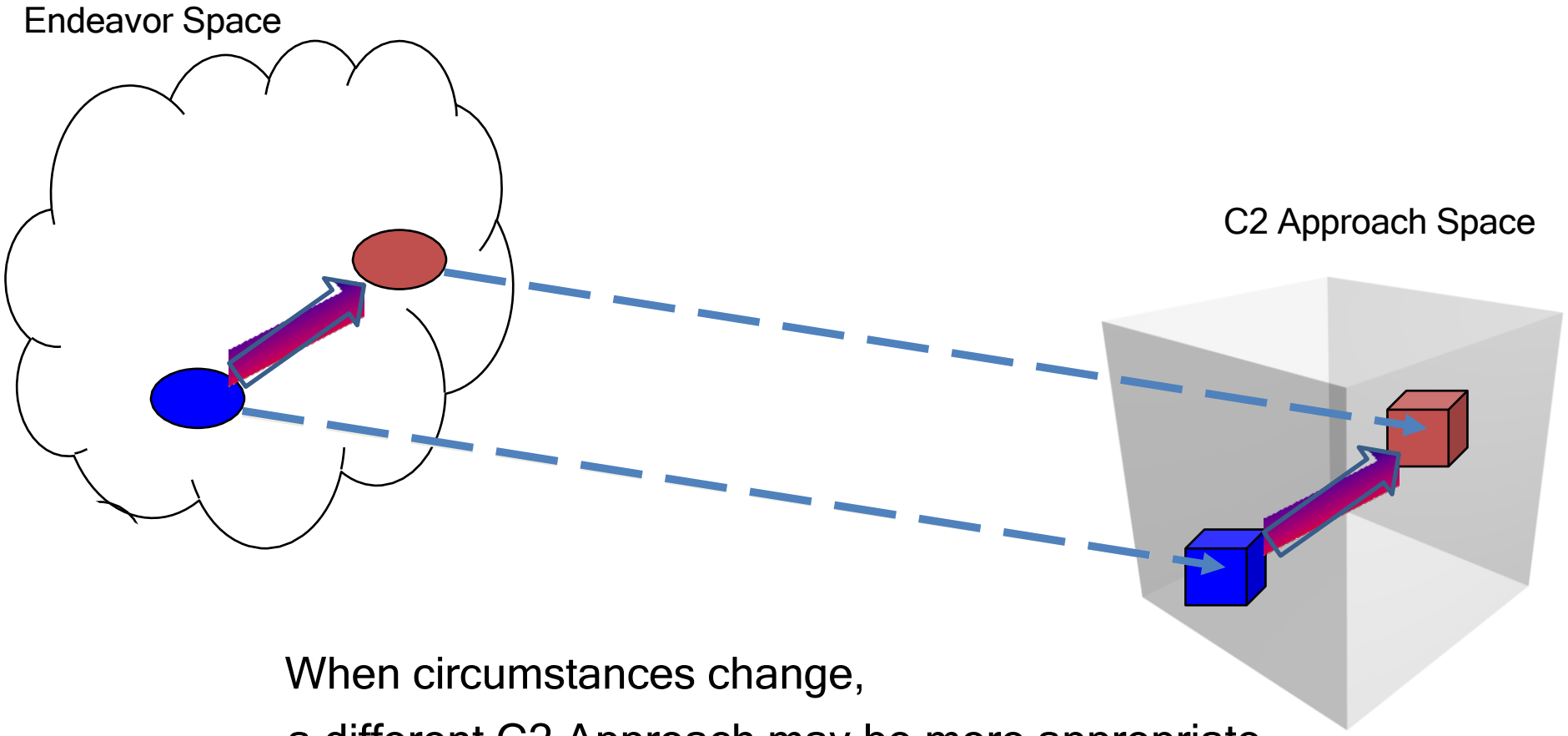

Distribution of Information

C2 Approach Space



C2 Agility

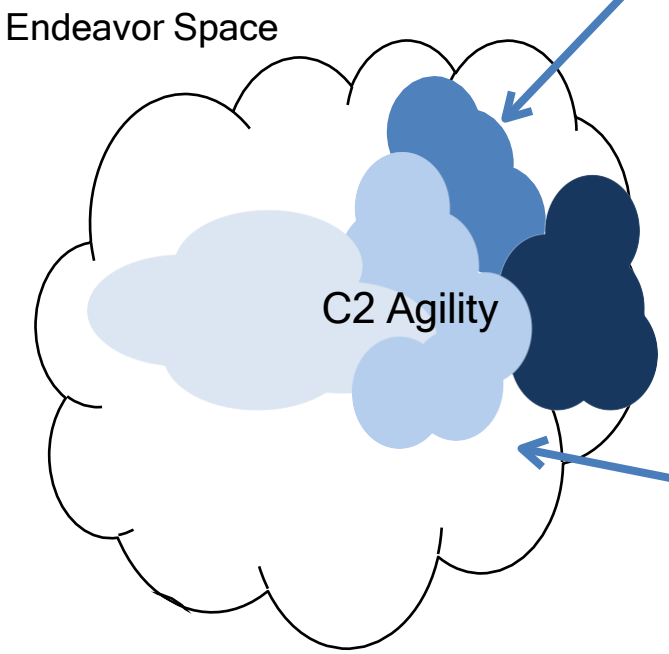
Step 2: Adapt C2 Approach as Circumstances Change



When circumstances change,
a different C2 Approach may be more appropriate.

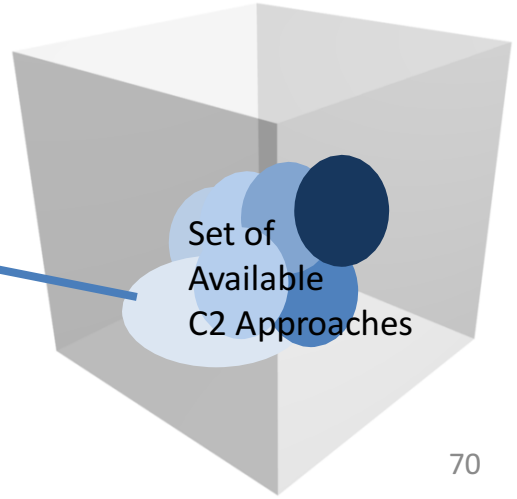
C2 Agility

- C2 Agility = f (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

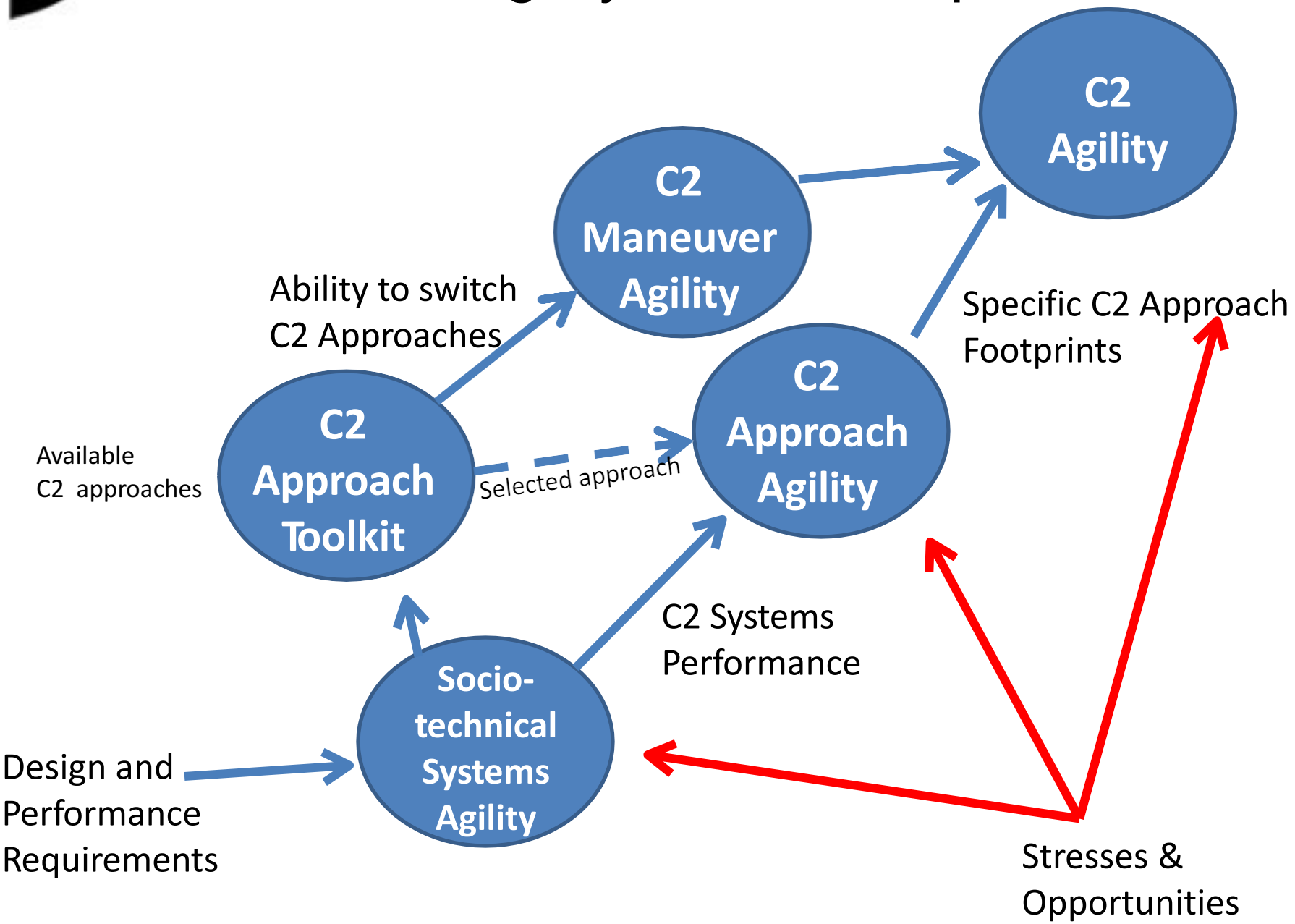
C2 Maneuver Agility is the ability to recognize the C2 approach appropriate for the circumstances and transition to this approach in a timely manner. It is a function of the set of C2 Approaches available to the entity.



Traditional v Agile C2

	Traditional C2	Agile C2
Approach	one way	set of options
Decision Rights	limited delegation of decision rights	as appropriate
Interactions	prescribed interactions	tailored
Information Dissemination	limited – need to know	access as appropriate - need to share
System Requirements	point to point support established processes	network support emergent processes

C2 Agility Relationships



Agenda

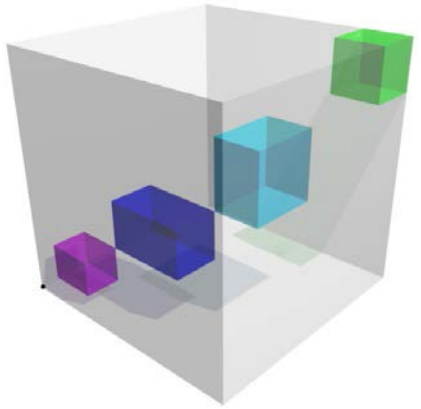
- Objectives
- Basics of Agility
- C2 Agility
- C2 Agility Hypotheses
- Validation
- Campaign of Experimentation
- Summary of Findings, Conclusions, and Way Ahead

What is an Hypothesis?

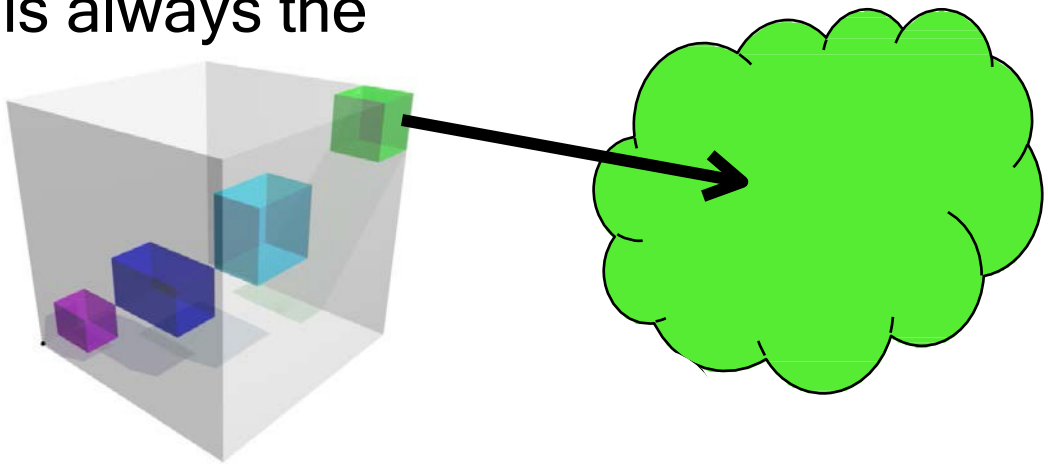
- A hypothesis is a clear statement articulating a plausible candidate explanation for observations. It should be constructed in such a way as to allow gathering of data that can be used to either accept the null hypothesis or reject the null in favour of the alternative hypothesis
- The case studies took a subjective qualitative approach when considering the acceptance or rejection of the null hypothesis
- The experiments took an objective quantitative approach when considering the acceptance or rejection of the null hypothesis
- Note: In this presentation only the alternative hypotheses are presented. The null hypotheses are implicit.

C2 Agility Hypotheses

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

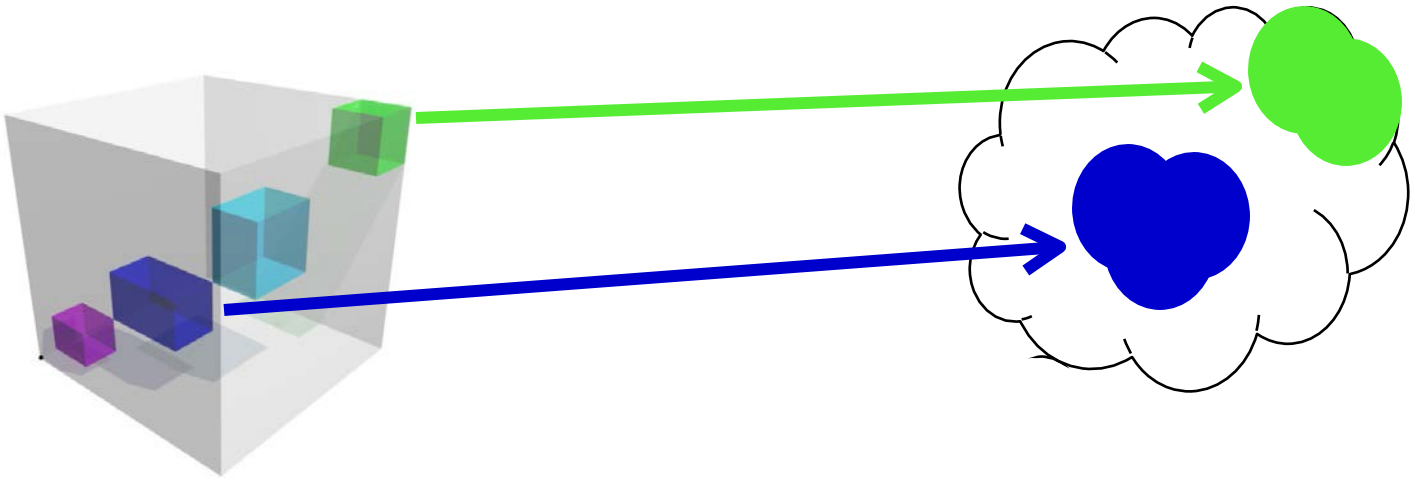


H2: No one approach is always the most appropriate



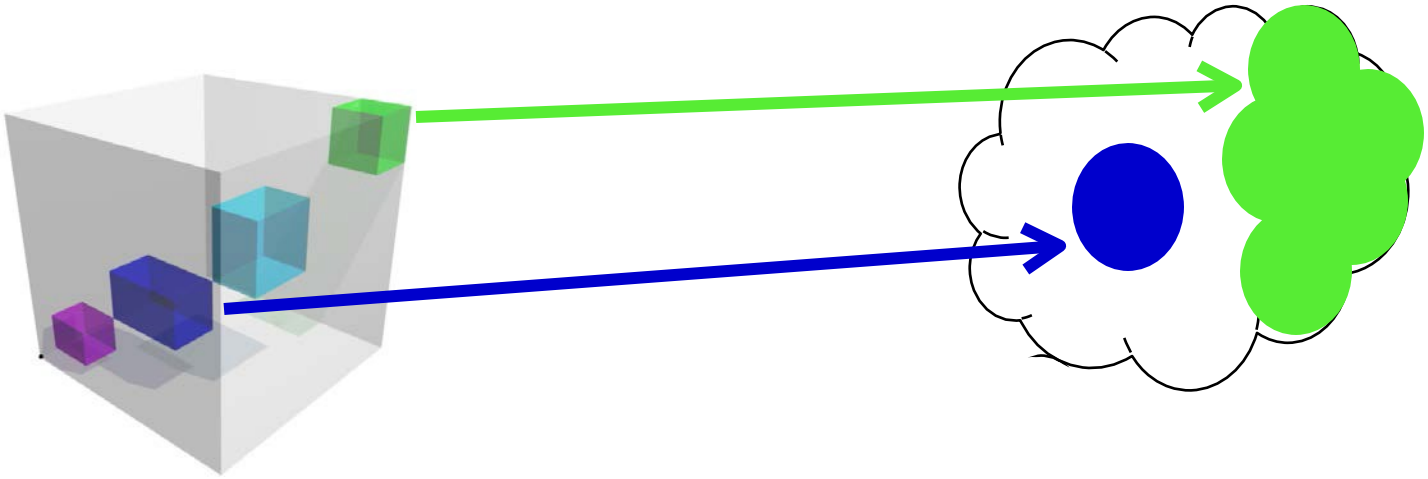
C2 Agility Hypotheses

H3: More network-enabled approaches are more appropriate for Complex Endeavors; while less network-enabled approaches are more appropriate for less complex missions/circumstances



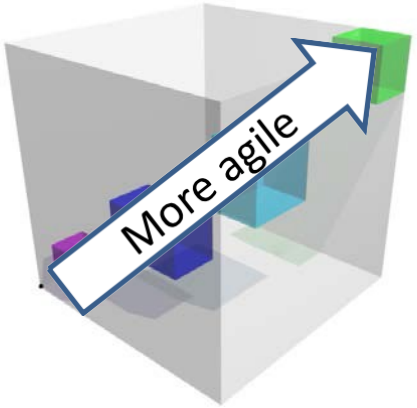
C2 Agility Hypotheses

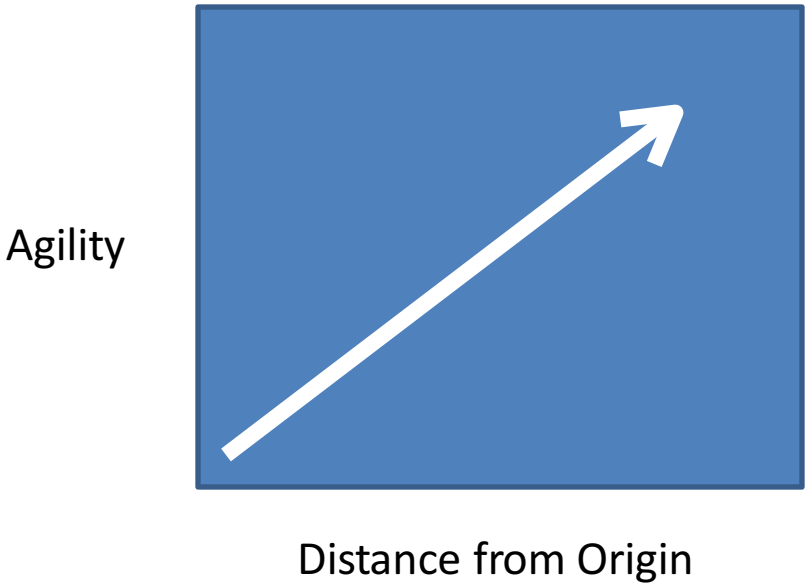
H4: More network-enabled approaches are more agile (have greater C2 Approach Agility)



C2 Agility Hypotheses

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

C2 Agility Hypotheses

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

Agenda

- Objectives
- Basics of Agility
- C2 Agility
- C2 Agility Hypotheses
- Validation
- Campaign of Experimentation
- Summary of Findings, Conclusions, and Way Ahead

Objectives of Validation Effort

- Clarity
  - Given that C2 Agility is a rich and nuanced concept and NATO is a very diverse alliance, SAS-085 wanted to ensure that its explanations, findings, and conclusions very clear and easy to understand
- Applicability
  - Given that C2 Agility is of more than academic interest, SAS-085 wanted to ensure that the concepts, metrics, and measures could be applied to real world organizations and situations
- Validity
  - The C2 Agility concept embodies a set of testable hypotheses; SAS-085 wanted to empirically test these hypotheses

Validation Approach

- Expert Validity – Does the model appear to be credible to those who are knowledgeable in the field?
  - Could we ourselves understand the concepts well enough to undertake a set of case studies and experiments
  - Peer Review process
- Construct Validity – Does the model include all of the relevant factors and relationships?
  - Could we observe critical aspects of the C2 Agility concept and related behaviors and outcomes in a variety of military and civil-military operations
  - Could we characterize and measure these behaviors and outcomes of interest in case studies and experiments
- Empirical Validity – Does the conceptual model produce the behaviors and results observed in the real world?
  - Are the hypotheses suggested by the model supported by the evidence derived from case studies and experiments

Agenda

- Objectives
- Basics of Agility
- C2 Agility
- C2 Agility Hypotheses
- Validation Approach
- Campaign of Experimentation (CoE)
- Summary of Findings, Conclusions, and Way Ahead

Case Studies were employed as well, but are not covered in this presentation

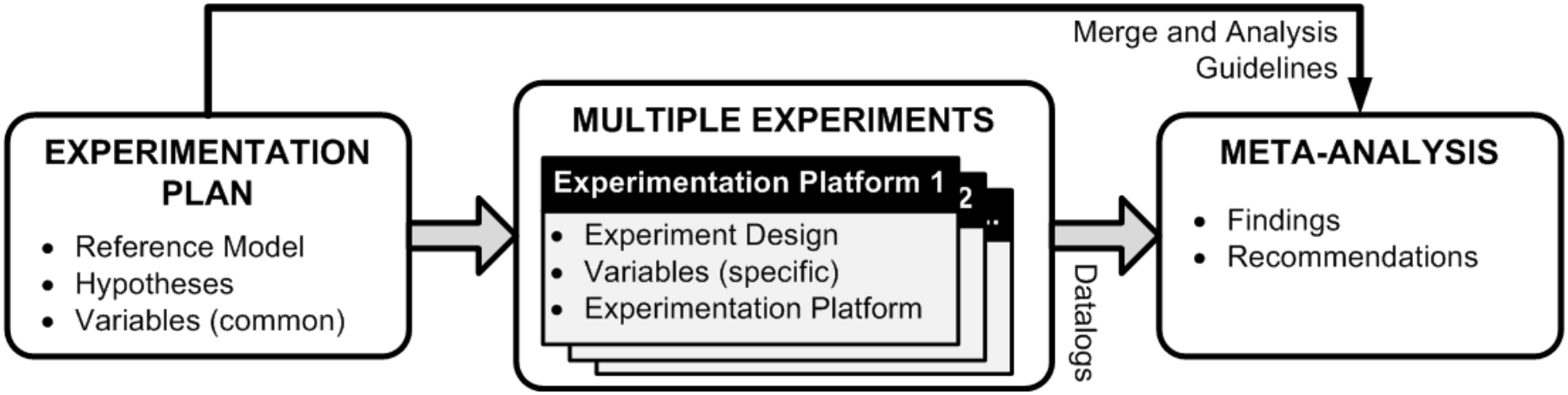
CoE Purpose

Contribute to the validation of the C2ACM by conducting multiple simulation-based experiments within the context of an overarching Campaign of Experimentation (CoE) that

- creates a rich set of empirical data
- tests a set of agility-related hypotheses

CoE Methodology

- The method followed is based on the prospective meta-analysis methodology in order to produce a more complete, robust and generalizable set of findings than summarizing multiple independent experiments



CoE Experimental Platforms

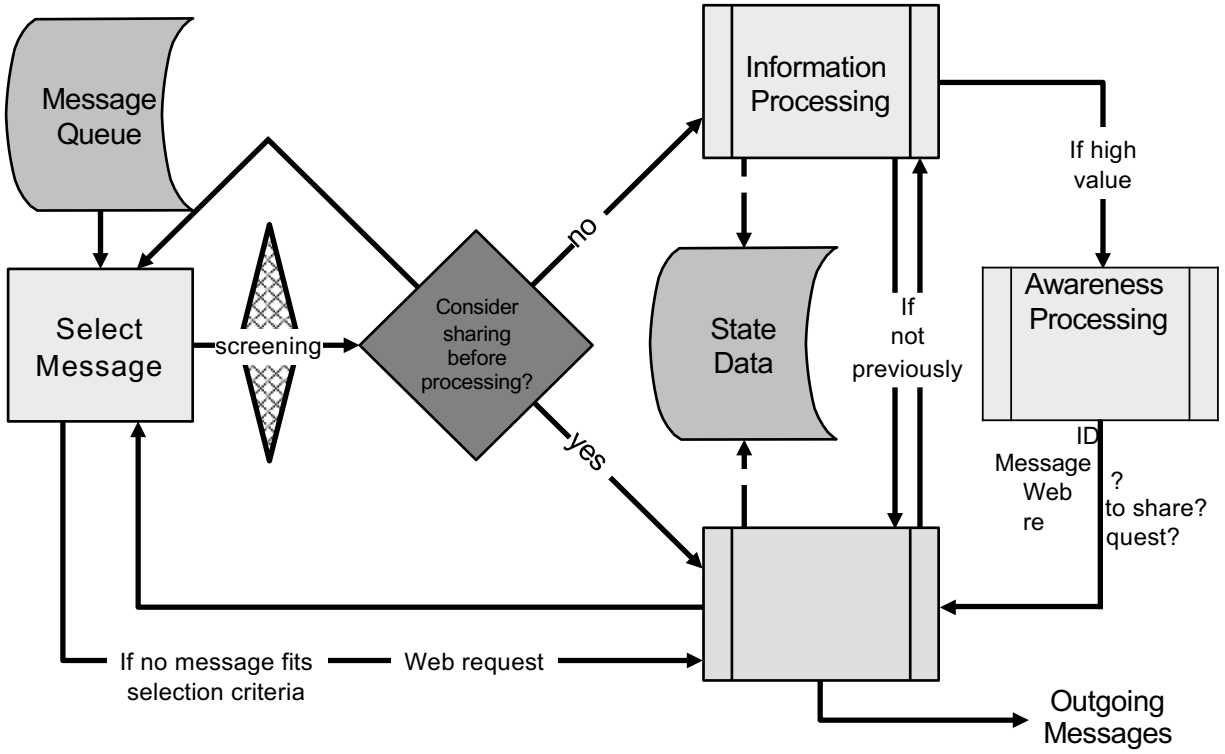
All experimental platforms are constructive agent-based simulations, each of which instantiates at least two C2 Approaches and simulates a variety of circumstances

- ELICIT: Scenario that finds the Who, What, Where and When of a terrorist attack. There are three variants:
  - ELICIT-IDA (U.S.A.)
  - abELICIT (Portugal)
  - ELICIT-TRUST (U.S.A.): agents are influenced by trust
- IMAGE (Canada): Multi-agency stabilization operation
- WISE (U.K.): Air and maritime support to land operation
- PANOPEA (Italy): Maritime counter-piracy operation

ELICIT Implementation

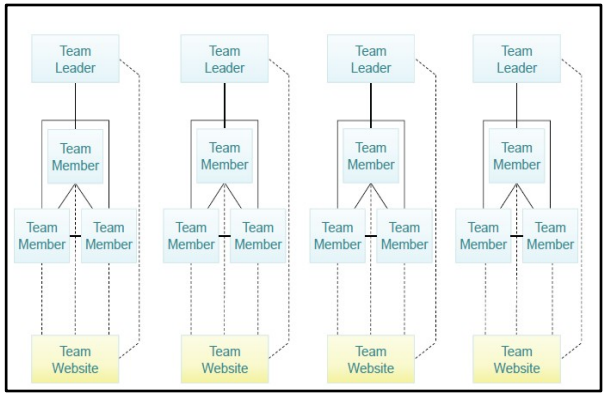
ELICIT-IDA, abELICIT

- Sensemaking agents developed (abELICIT) with parameters to vary the capability and behavior of agents during experiments

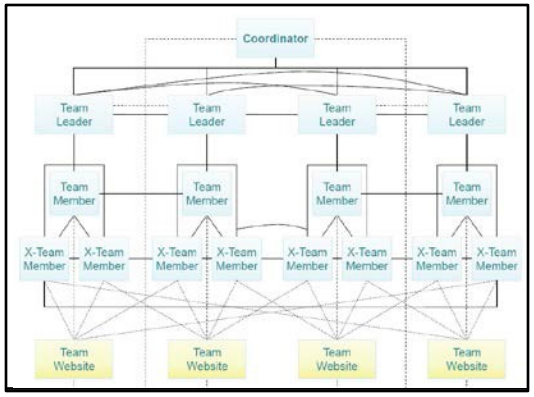


ELICIT

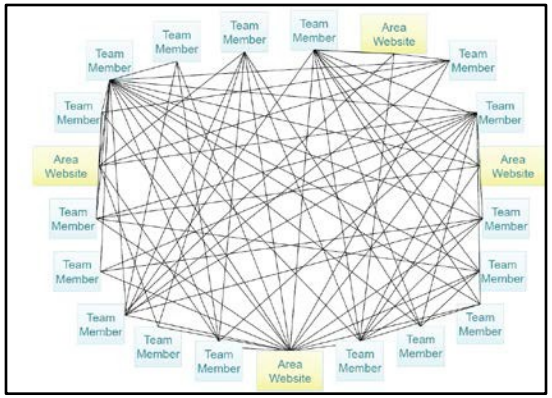
- ELICIT is a DoD CCRP developed experiment platform testing the ability of entities to solve a hidden profile problem for a fictitious terrorist threat
- Originally designed to test various hypotheses between the performance of traditional hierarchical and edge organizations



Conflicted



Collaborative



Edge

ELICIT-TRUST

- C2 environments will exist in situations where entities do not trust or there is uncertainty with regard to the behavior of others in the Collective
- ELICIT-TRUST implements sharing behavior between nodes based on trust estimate of other agents
- Trust is a function of competence and willingness.
- Trust evolves according to Bayesian models and agents adapt their behaviors based on estimated trust of neighboring entities
- Communication network effects degrade the flow of information

ELICIT Experiment Endeavor Spaces

	ELICIT-IDA	ELICIT-TRUST	abELICIT
Self	Network damage	Message/Drop rates	Infostructure degradation
		Trust	Agent performance
		Selfishness	Organisation disruption
Environment	Challenge		Key information available
	Noise in information		
	Cognitive complexity		

IMAGE

- IMAGE is a complexity comprehension tool augmented with software agents that deliberate and act according to rules that comply as much as possible with N2C2M2 theory
- The scenario involves multiple organizations that try to secure and stabilize the failing state by using a comprehensive approach

Canadian

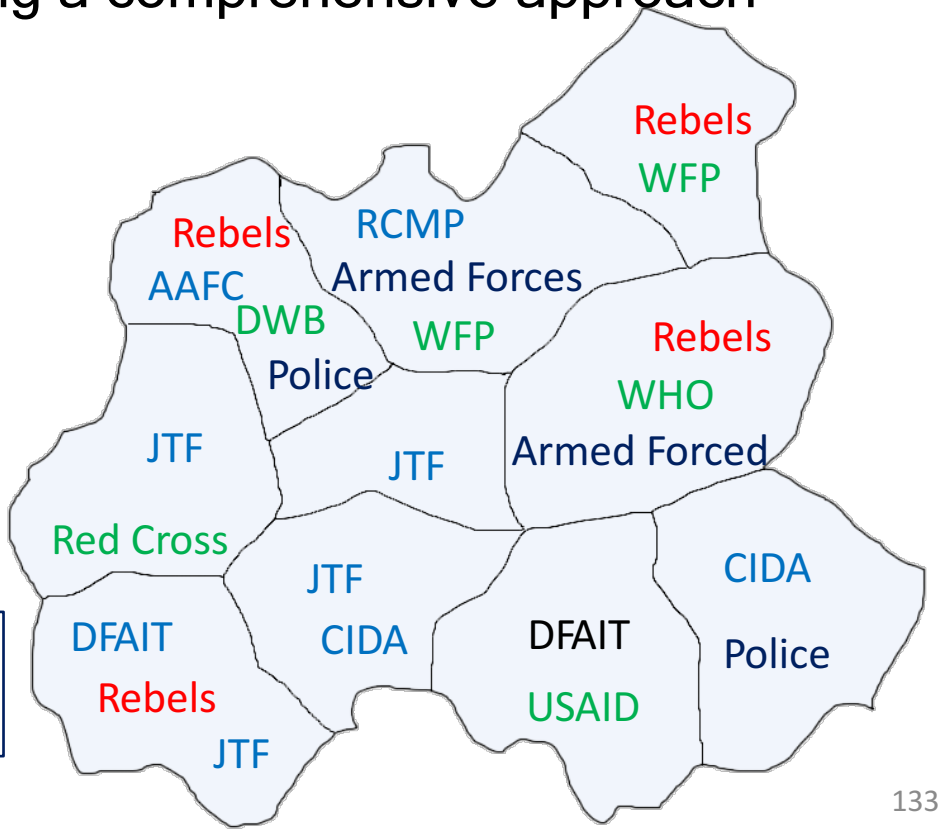
JTF: Joint Task Force
AAFC: Agriculture Canada
CIDA: Canadian International Dev. Agency
DFAIT: Foreign Affair and Int. Trade Canada
RCMP: Royal Canadian Military Police

International

DWB: Doctor Without Border
WHO: World Health Organization
WFP: World Food Program
Red Cross
USAID: US Agency Inter. Devel.

Local

Armed forces
Police



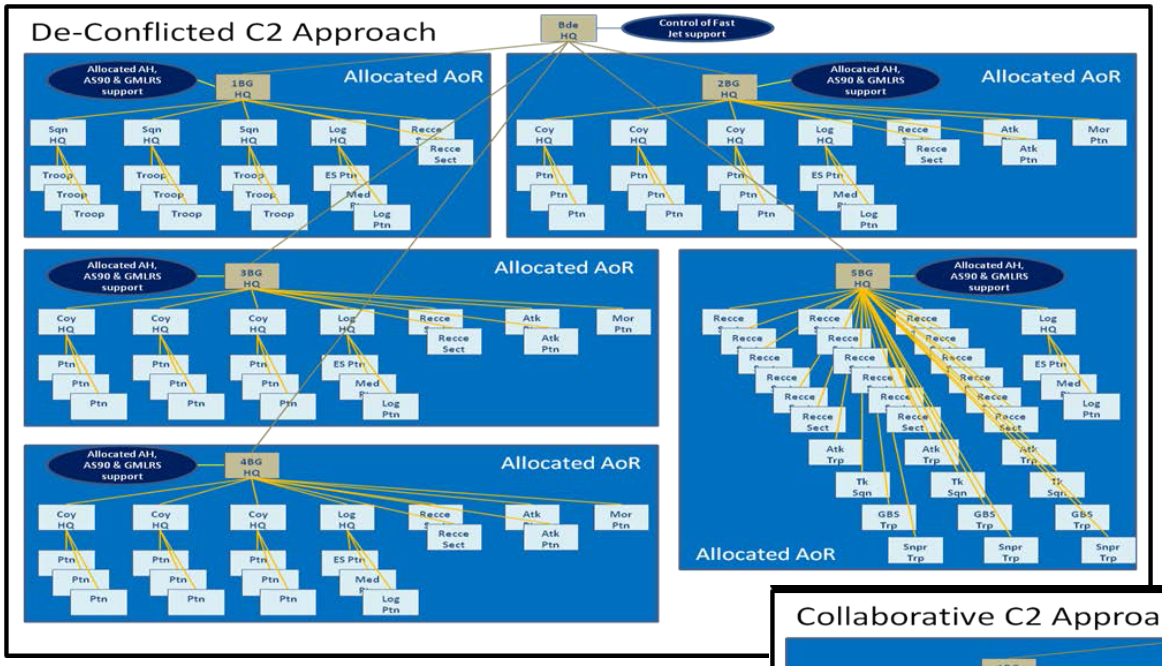
IMAGE

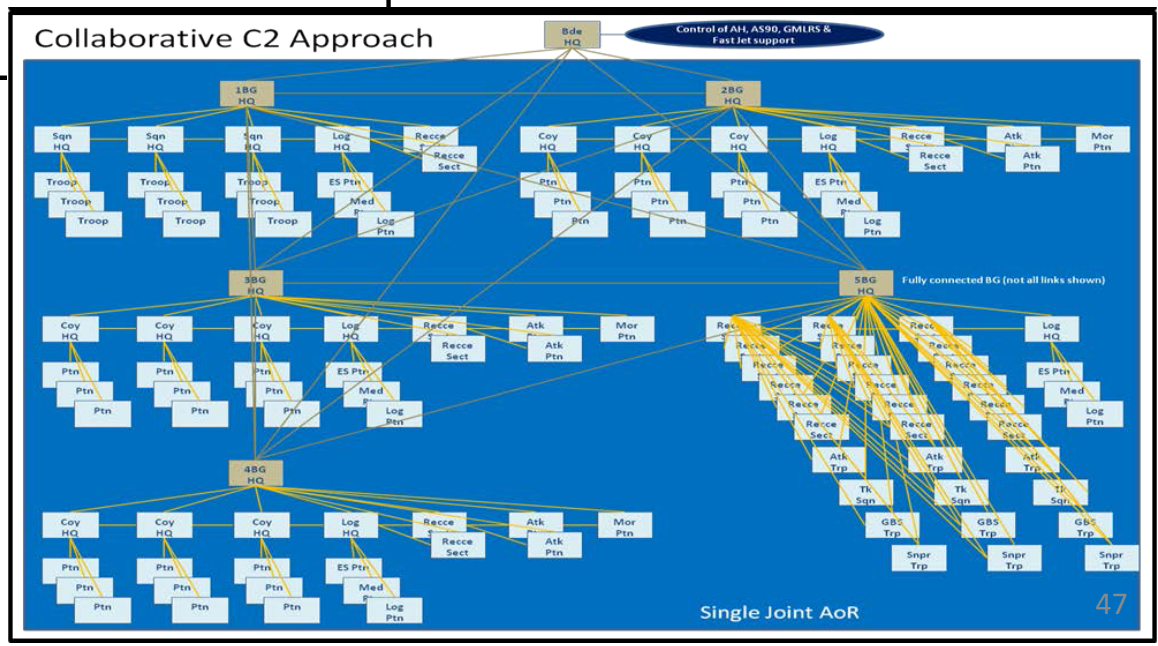
C2 Approach	Allocation of Decision Rights to the Collective	Patterns of Interaction among Entities	Distribution of Information among entities
Conflicted	Each organization decides of its unit locations and activities	Between units of the same organization	Between units of the same organization
De-conflicted	Each organization decides on its unit locations and non-conflicting activities	With organizations having collocated units for preventing conflicting activities	Variables shared instantly between organizations having collocated units
Coordinated	Like in De-Conflicted but interacting activities are considered first with collocated units	With organizations having collocated units for considering interacting activities	Like in De-Conficted + variables shared with 5 non-collocated units (delay: 5 iter)
Collaborative	All activities and unit locations are decided collectively	With all organizations for deciding unit locations and activities.	Same as coordinated but with any number of units (delay 3 iter.)

WISE

- The Wargame Infrastructure and Simulation Environment (WISE) is a Land focused C2 model with representation of air and maritime support to Land operations at the system level
- The scenario simulates a failing state that is experiencing internal conflict. The central government has invited a NATO coalition to stabilize the country
- The UK operation represents a brigade size operation with the specific intent of clearing insurgents from a major urban area
- WISE represented degraded conditions within the brigade operational area by varying the quality of battlefield communication

WISE

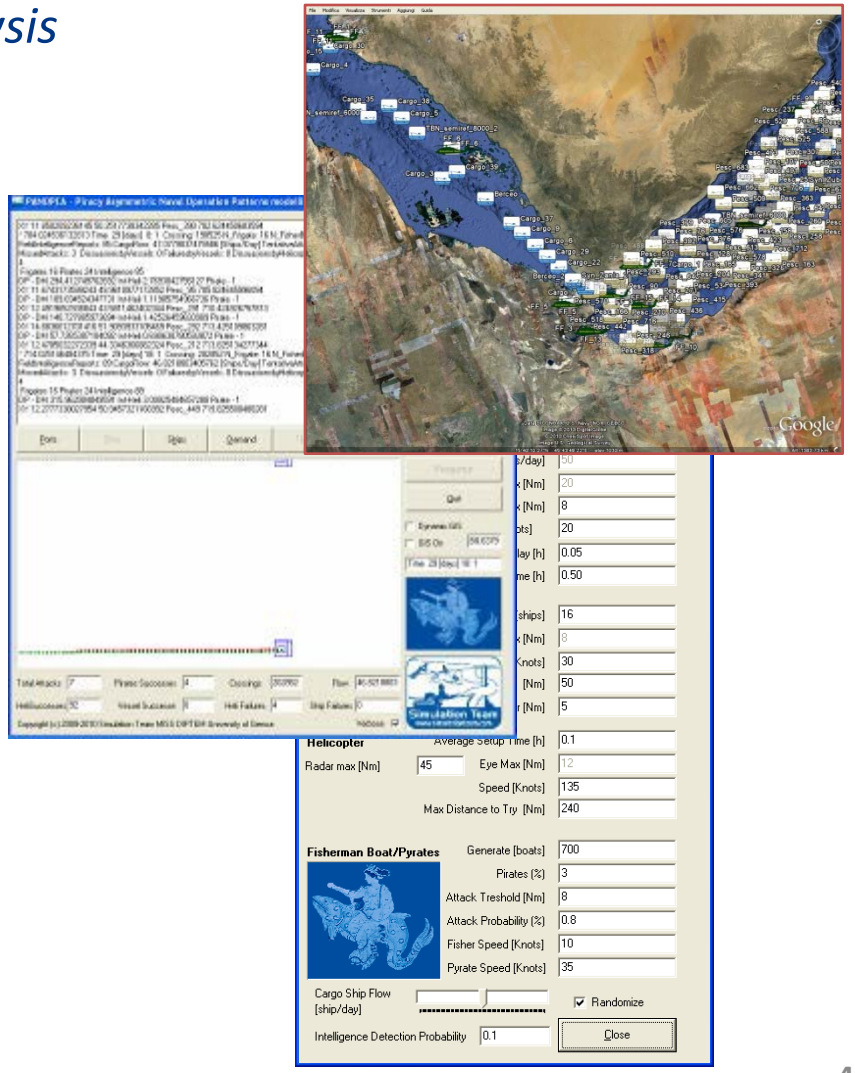

De-Conflicted C2 Approach
Bde HQ
Control of Fast Jet support
Allocated AH, AS90 & GMLRS support
1BG HQ
Allocated AoR
2BG HQ
Allocated AoR
3BG HQ
Allocated AoR
4BG HQ
Allocated AoR
5BG HQ
Allocated AoR


Collaborative C2 Approach
Bde HQ
Control of AH, AS90, GMLRS & Fast Jet support
1BG HQ
2BG HQ
3BG HQ
4BG HQ
5BG HQ
Fully connected BG (not all links shown)
Single Joint AoR

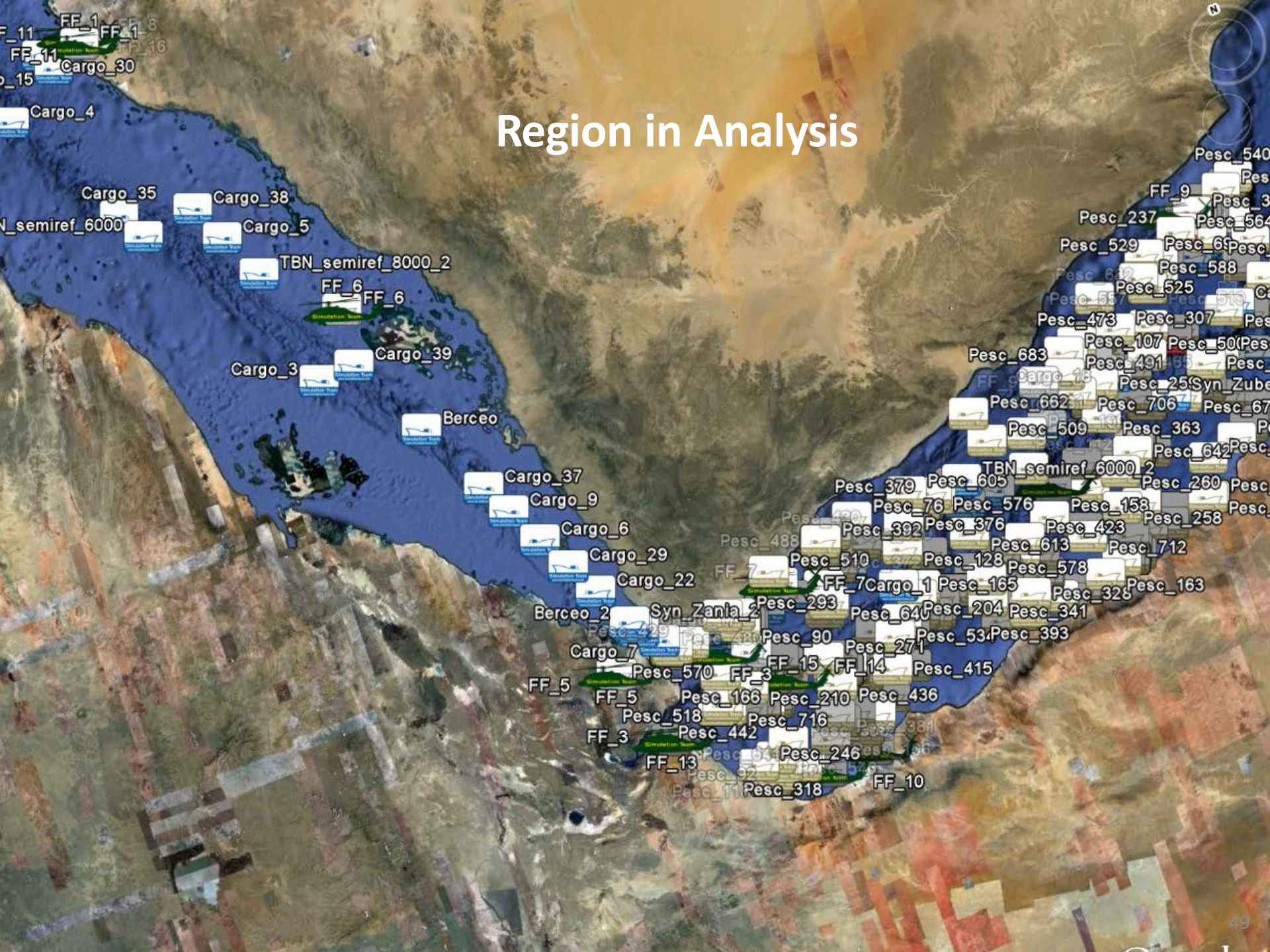
PANOPEA

***P**iracy **A**symmetric **N**aval **O**peration*
***P**atterns modeling for **E**ducation & **A**nalysis*

- PANOPEA is a simulator for reproduction of anti-piracy operations and for evaluating the different approaches defined in NEC C2M2
- PANOPEA reproduces military frigates and helicopters, ground base, cargos, fisherman, yachts traffic and pirates
- Units are managed by intelligent software agents

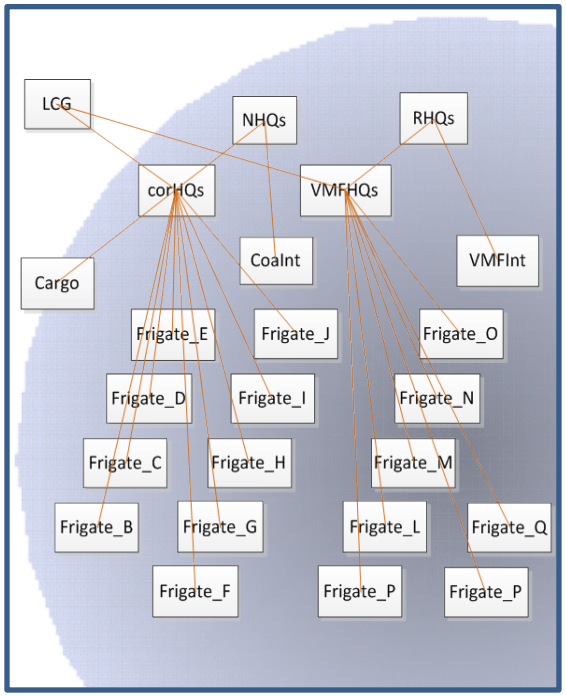


Region in Analysis

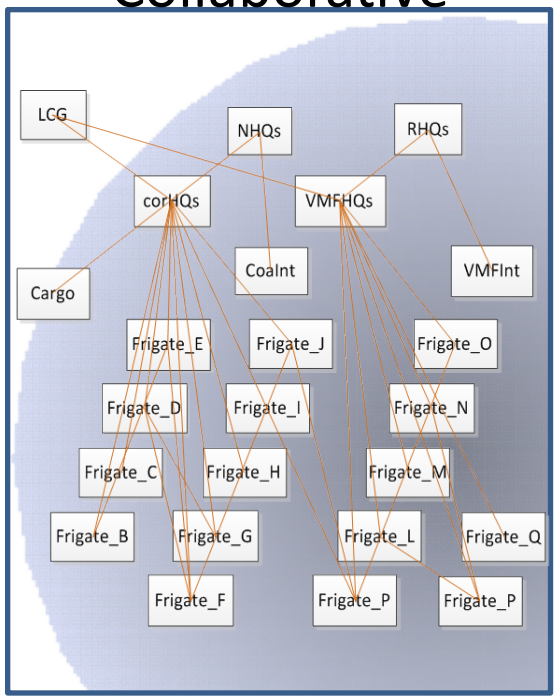


PANOPEA

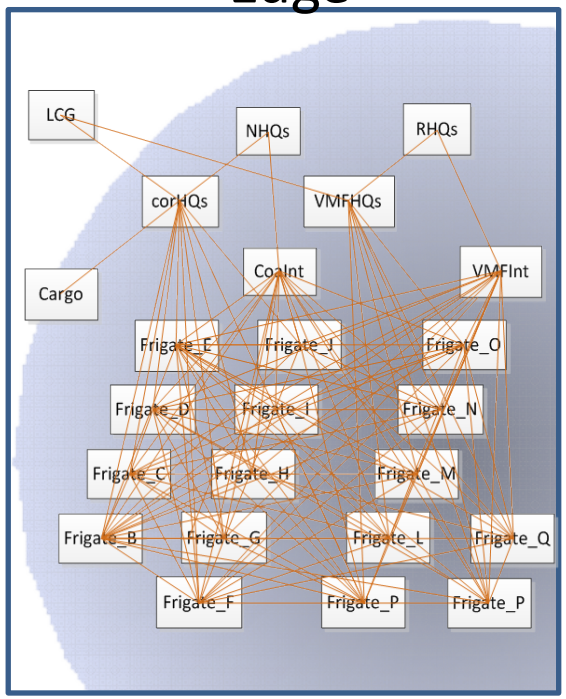
De-Conflicted



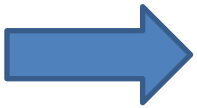
Collaborative



Edge



- Ship decision-making capability
- Intelligence DM capability
- Number of pirates
- Weather condition
- Misleading information



Endeavour Space

C2 Approaches Tested

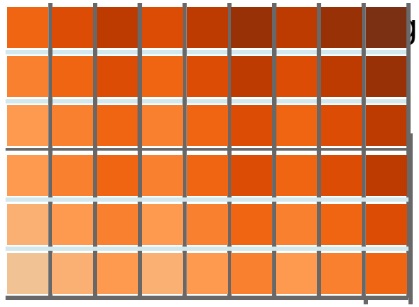
The differences among the experimental instantiations of the C2 approaches was investigated and these were found to be insignificant for the purposes of the CoE

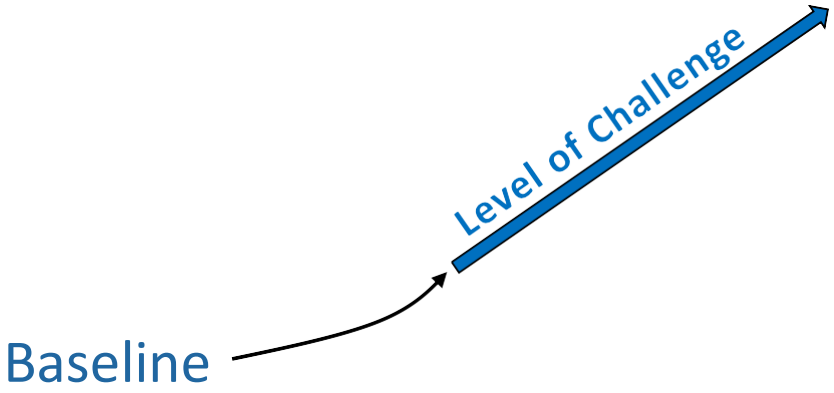
	ELICIT-IDA (USA)	ELICIT-TRUST (USA)	abELICIT (Portugal)	IMAGE (Canada)	WISE (UK)	PANOPEA (Italy)
Conflicted		X		X		
De-Conflicted	X	X		X	X	X
Coordinated	X	X	X	X		
Collaborative	X	X	X	X	X	X
Edge	X	X	X			X

Not all of the experiments implement all of the C2 Approaches

Creating an Endeavour Space

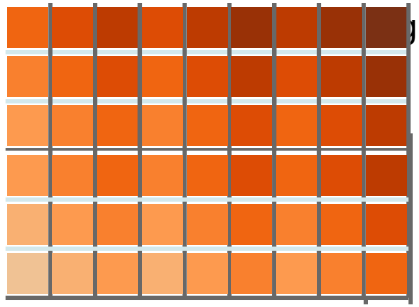
- The Endeavor Spaces were populated by combining all possible values of multiple variables, each one corresponding to an aspect of the situation
- Heat maps show the progressive degree of challenge of the Endeavour Spaces
  - Darker shades of orange represent most challenging circumstances
  - Values were normalized across the experiment

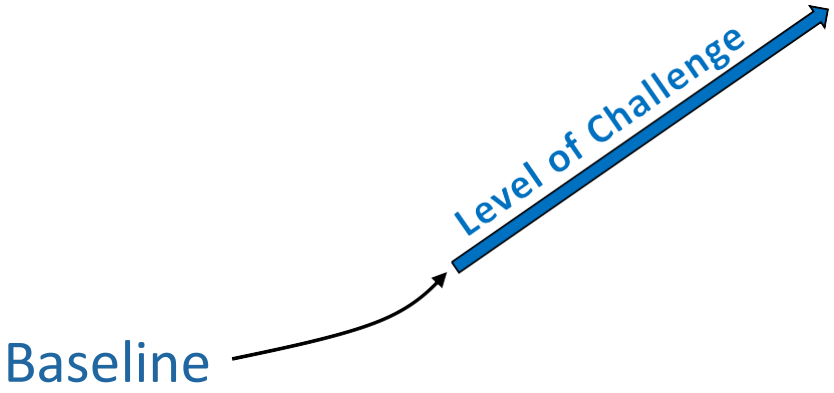




Creating an Endeavour Space

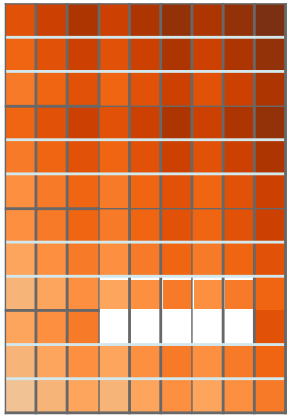
- The Endeavor Spaces were populated by combining all possible values of multiple variables, each one corresponding to an aspect of the situation
- Heat maps show the progressive degree of challenge of the Endeavour Spaces
  - Darker shades of orange represent most challenging circumstances
  - Values were normalized across the experiments



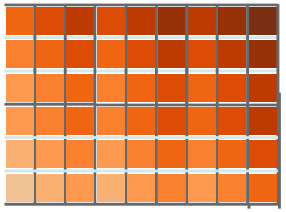


CoE Endeavour Spaces

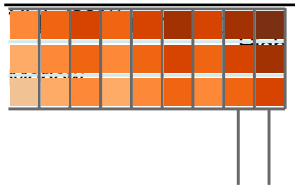
ELICIT-IDA



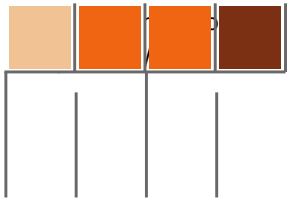
IMAGE



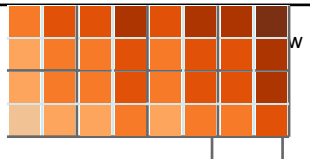
ELICIT-TRUST



WISE



PANOPEA

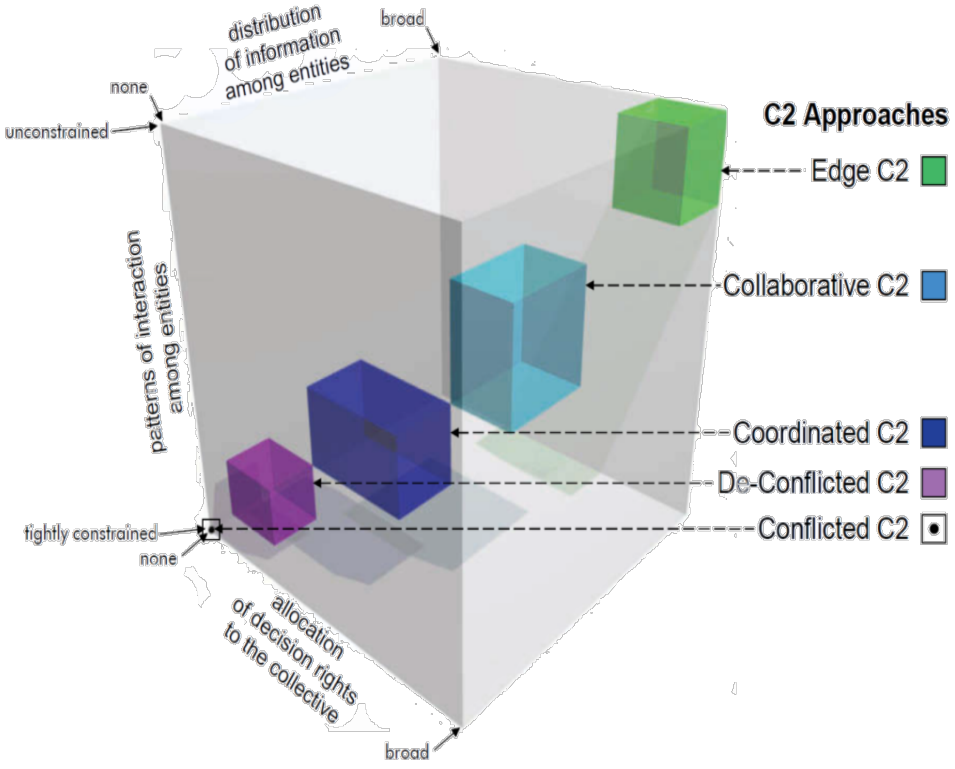


0.0 1.0

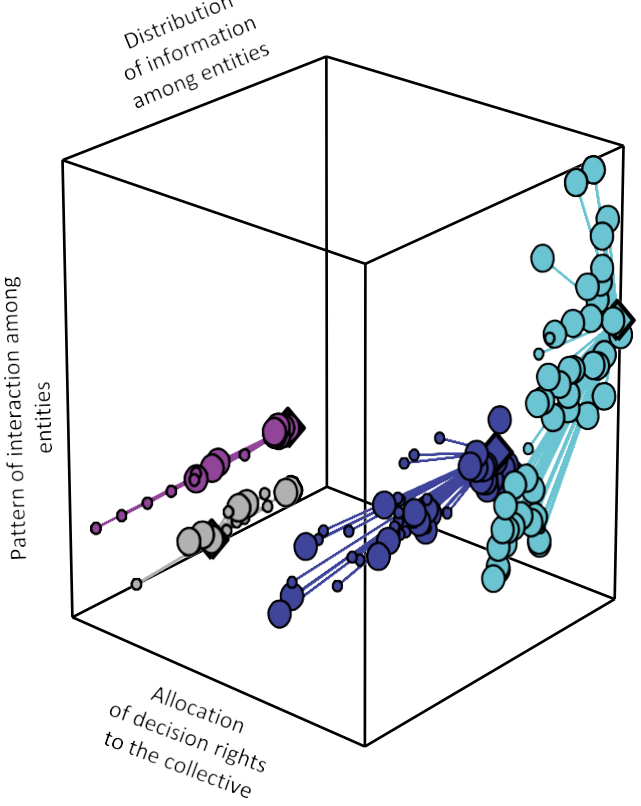
Approaches in the C2 Approach Space

H1: Each of the NATO C2 Maturity Model approaches is located in a distinct region of the C2 Approach Space

Theoretical Locations

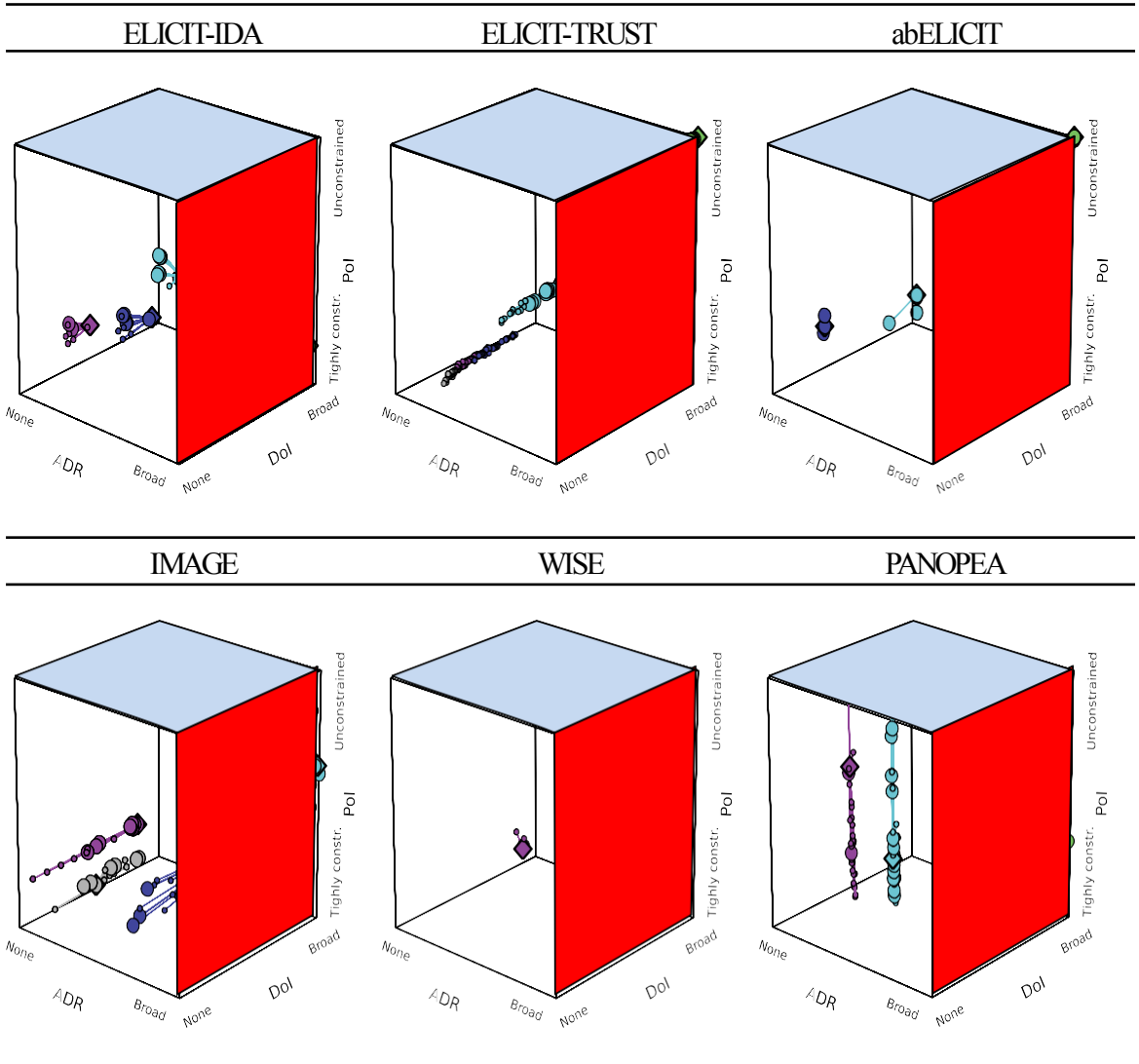


Measured Locations (IMAGE)



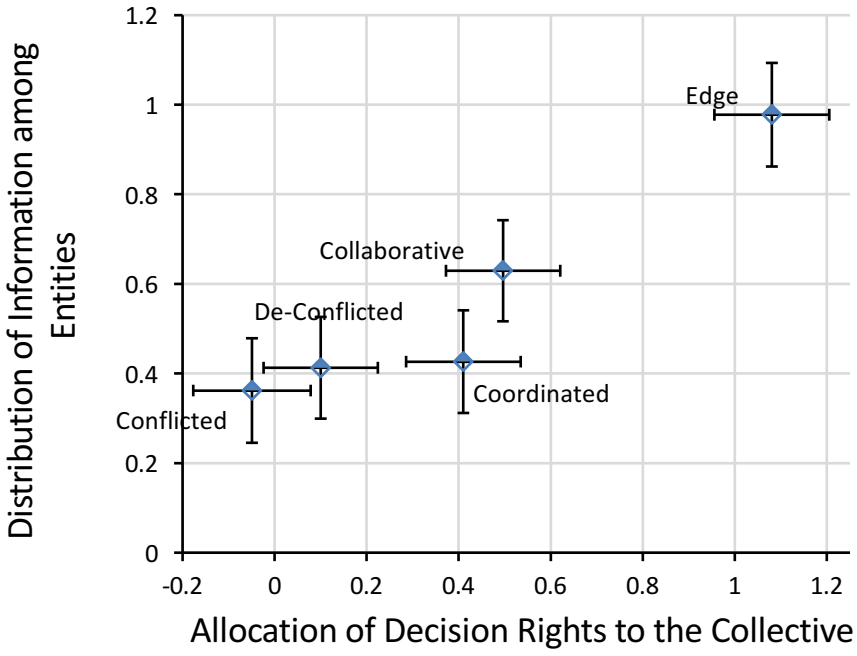
Success Failure Baseline Degraded Conditions

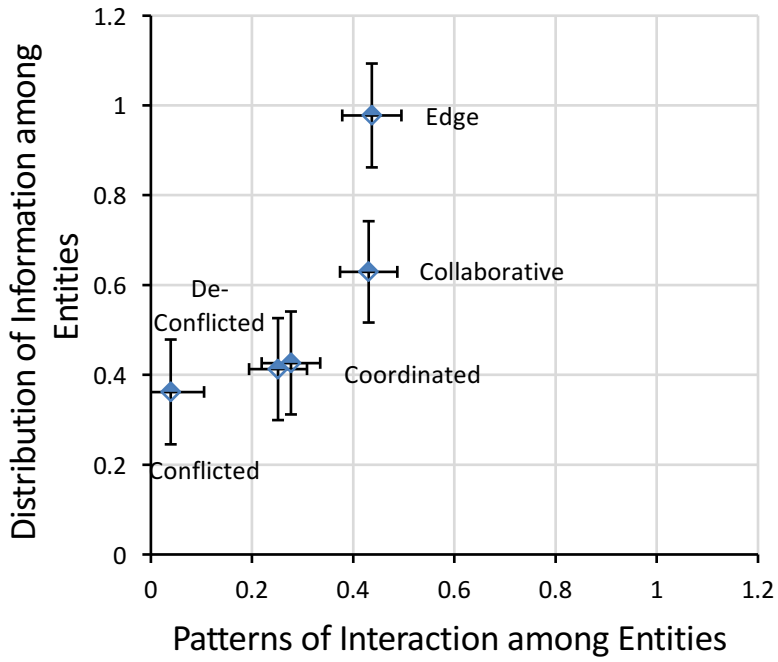
Approaches in the C2 Approach Space



C2 Approach Locations: Combined Results

95% confidence intervals

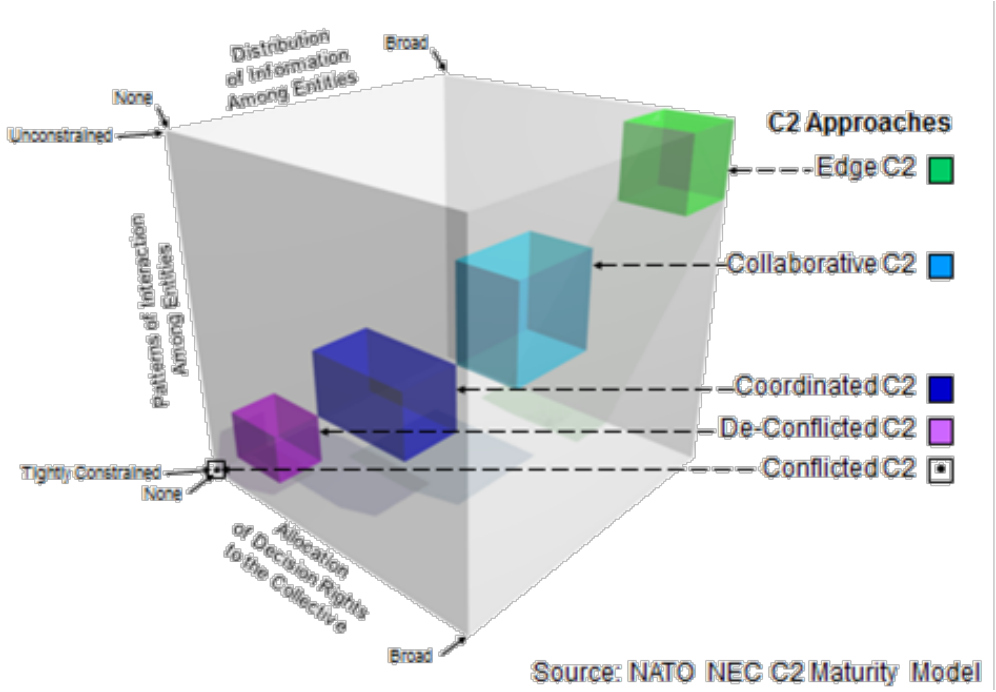




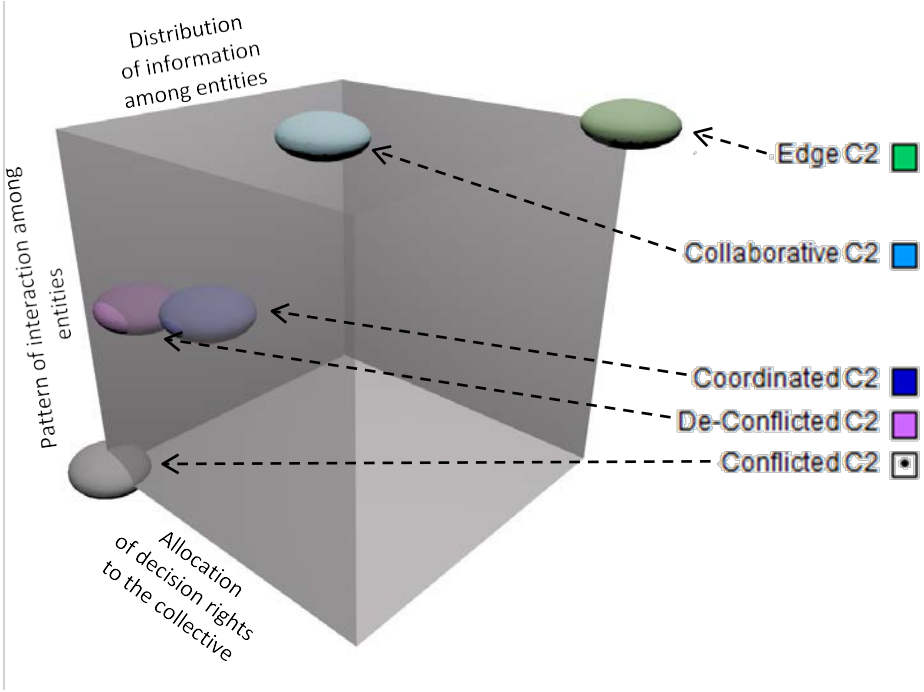
Combined results show that C2 approaches are located in distinct regions of the C2 Approach Space

C2 Approach Locations: Combined Results

Theoretical Model



Experimental Results

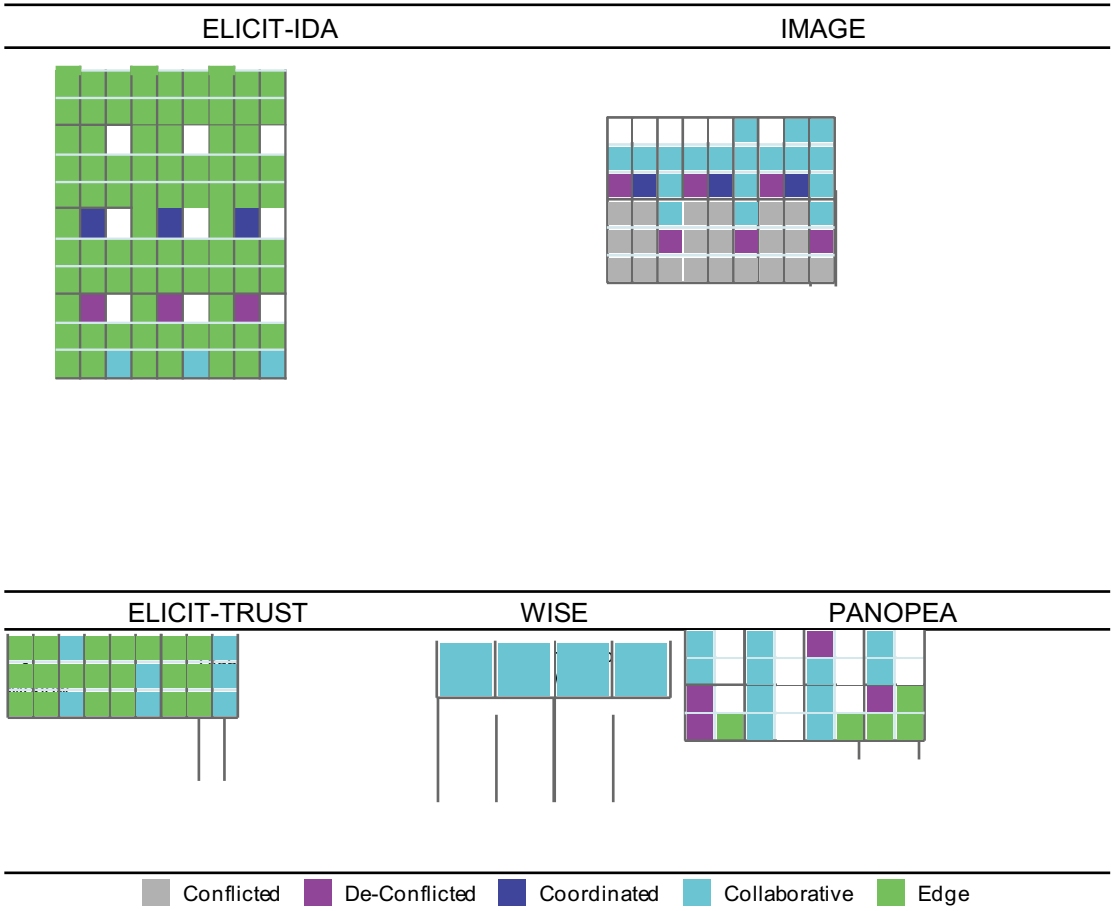


Combined results show that C2 approaches are located in distinct regions of the C2 Approach Space

No 'One Size' Fits All

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

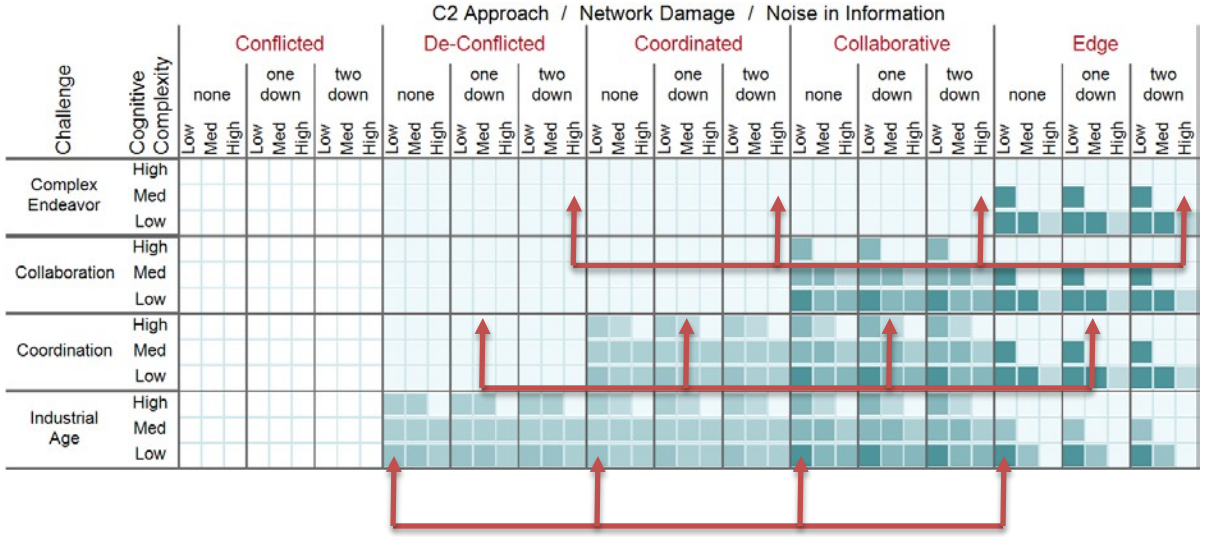
H3: More network-enabled approaches to C2 are more appropriate for more challenging circumstances; however, less network-enabled C2 approaches to C2 are more appropriate for some circumstances



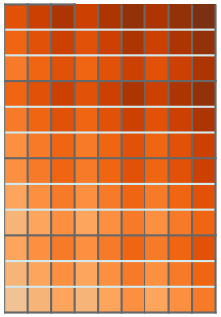
More Network-Enabled = More Agility

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

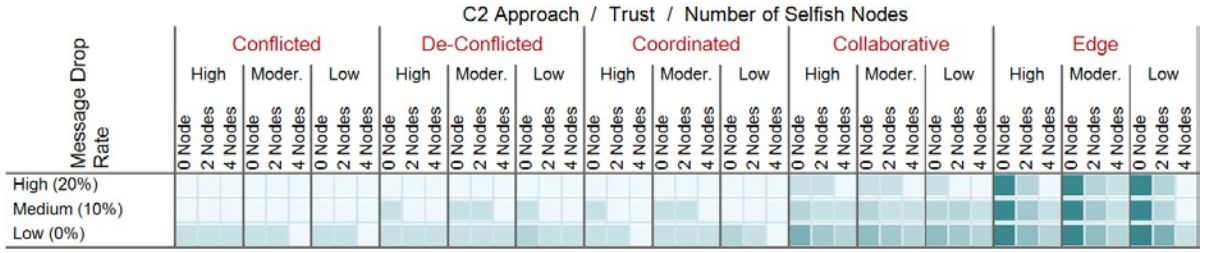
ELICIT-IDA



Same circumstance tested un different C2 Approaches



ELICIT-TRUST



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

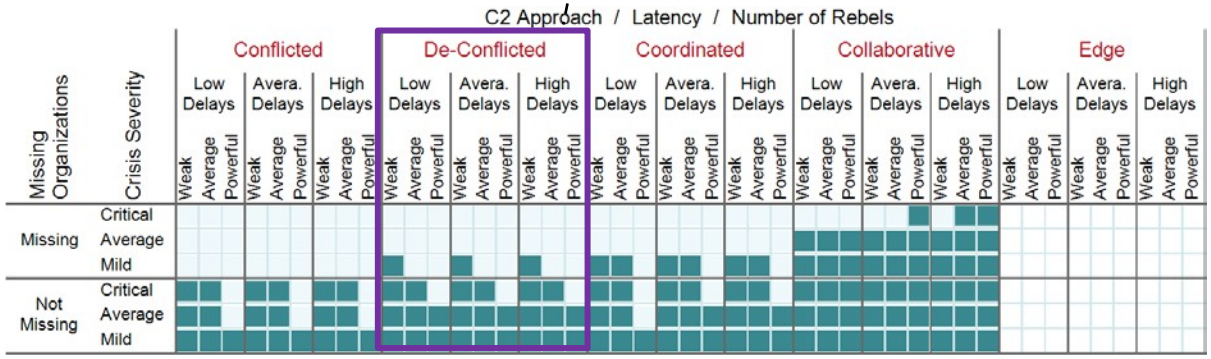
More Network-Enabled = More Agility

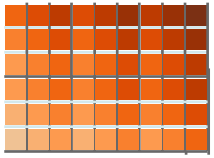
IMAGE

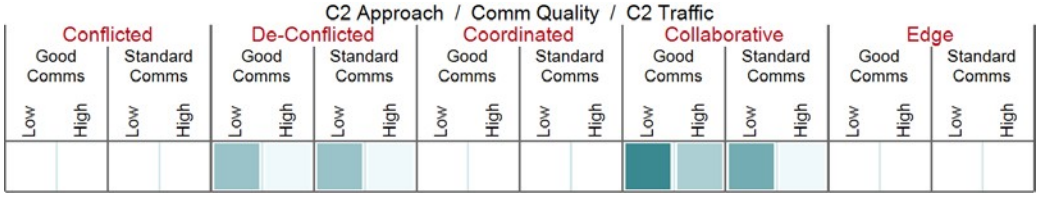
WISE

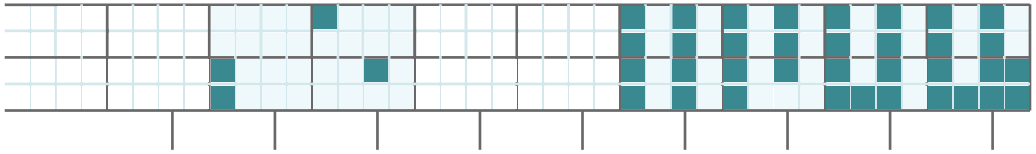
PANOPEA

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





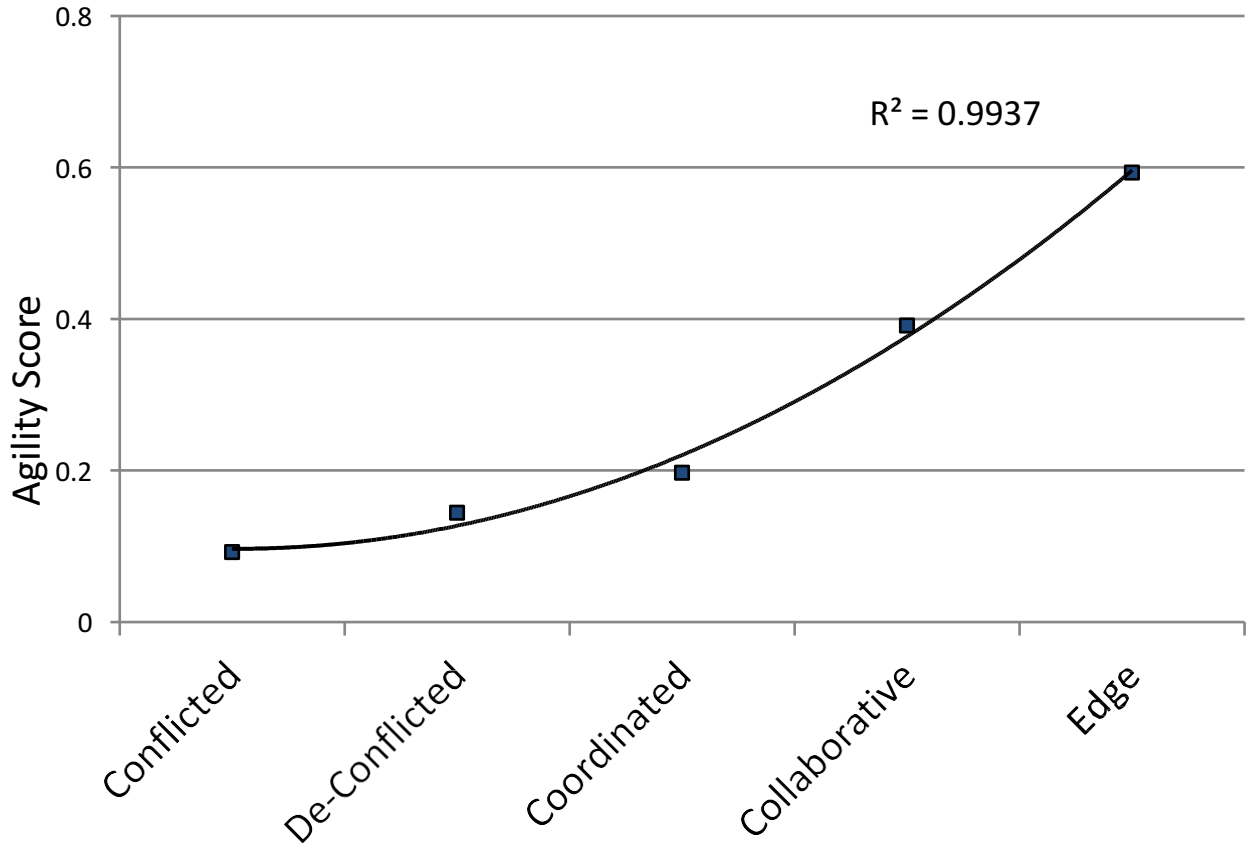




- Darker shades of teal correspond to higher levels of mission success (1.0), lighter ones to failure (0.0)
- Blank squares represent non-simulated cases

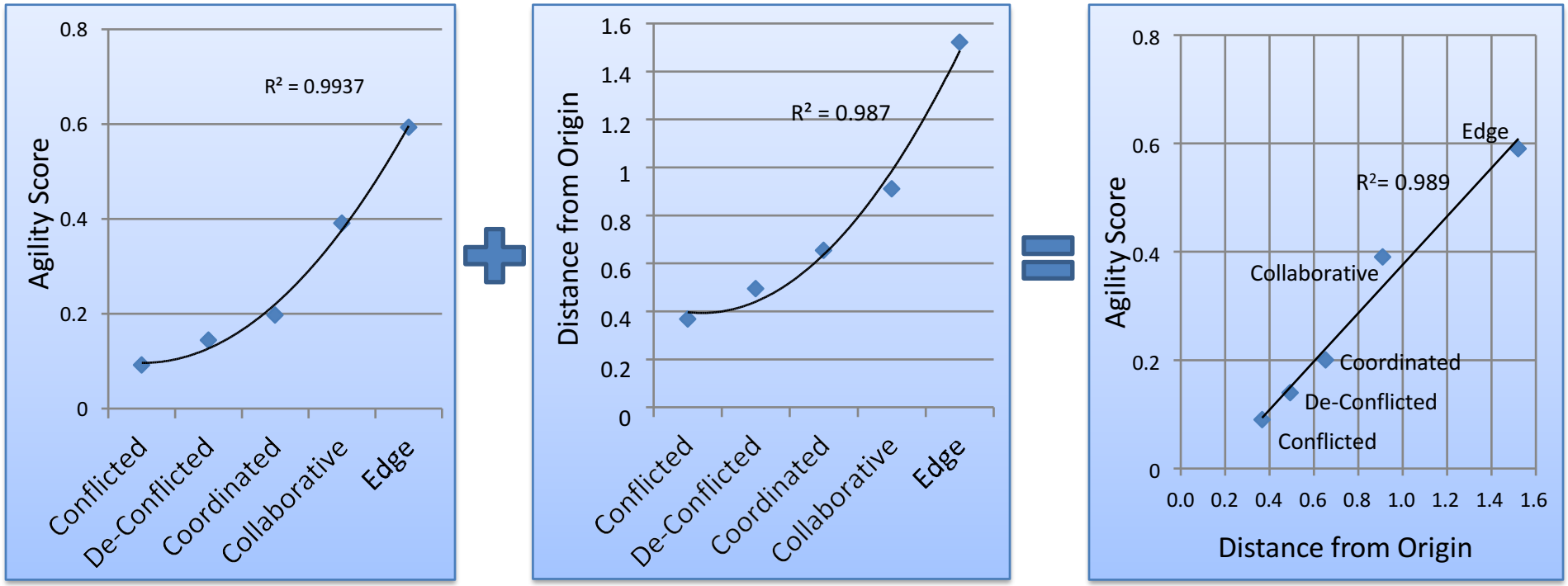
More Network-Enabled = More Agility

- Results suggest that Agility accelerates as C2 approaches become more network-enabled
- The relation between C2 Approach and Agility Score is quadratic ($R^2 = 0.99$)



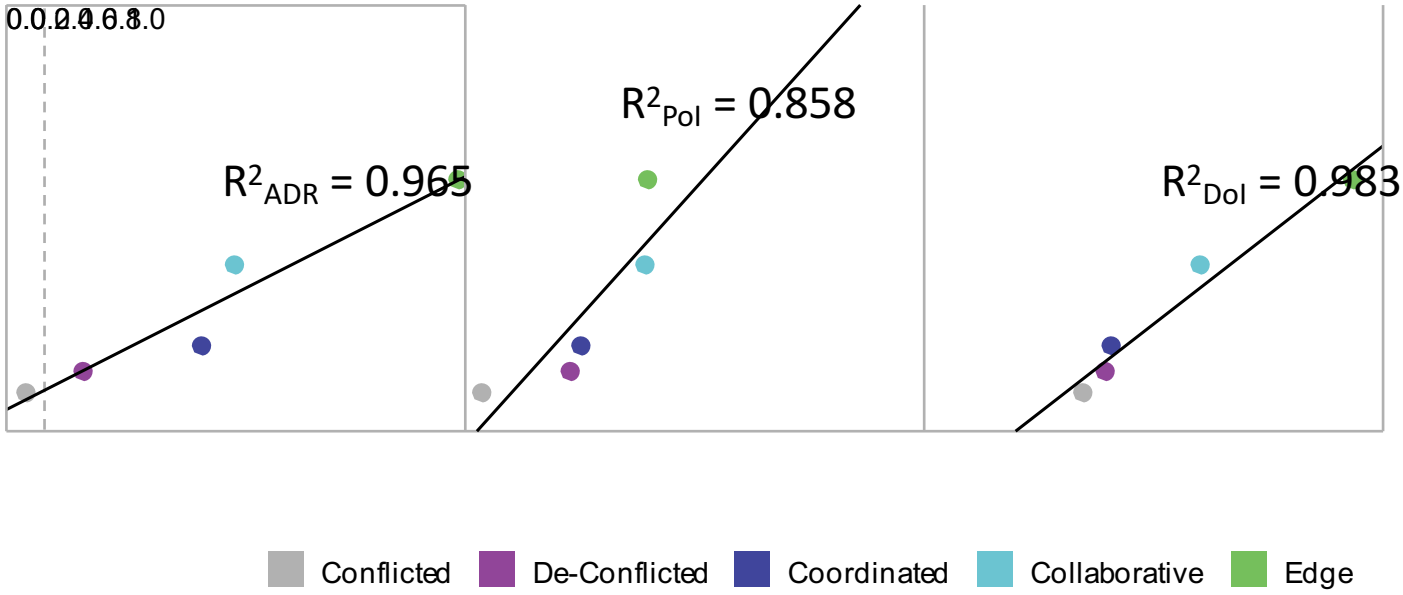
More Network-Enabled = More Agility

- There are a few possible explanations for the quadratic effect:



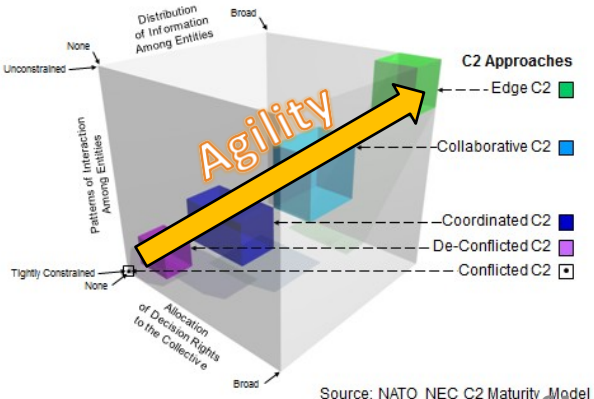
C2 Approach Space → Agility

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

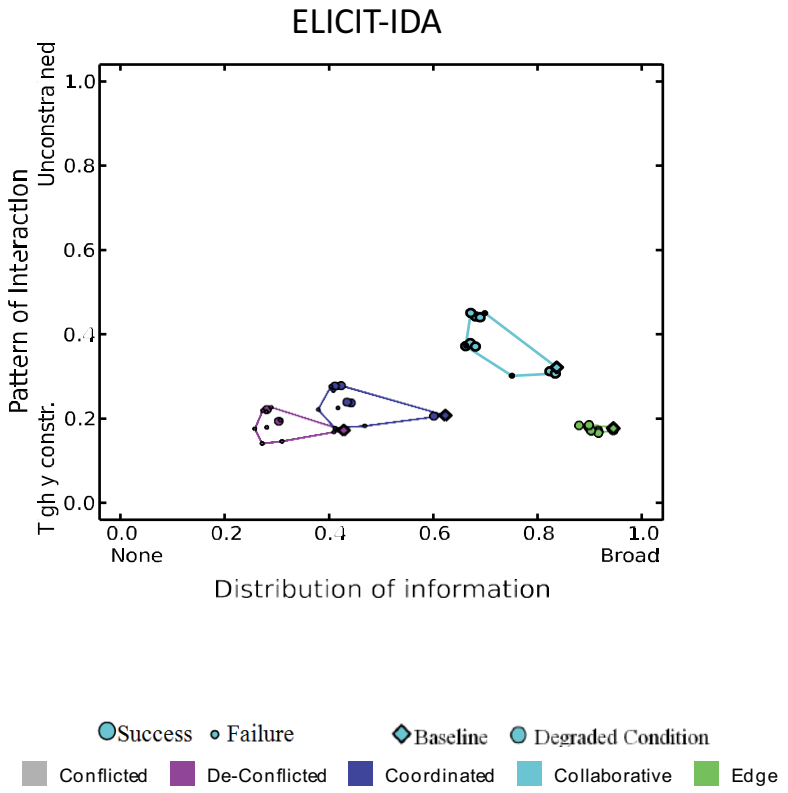


Source: NATO NEC C2 Maturity Model

Location Variations in C2 Approach Space

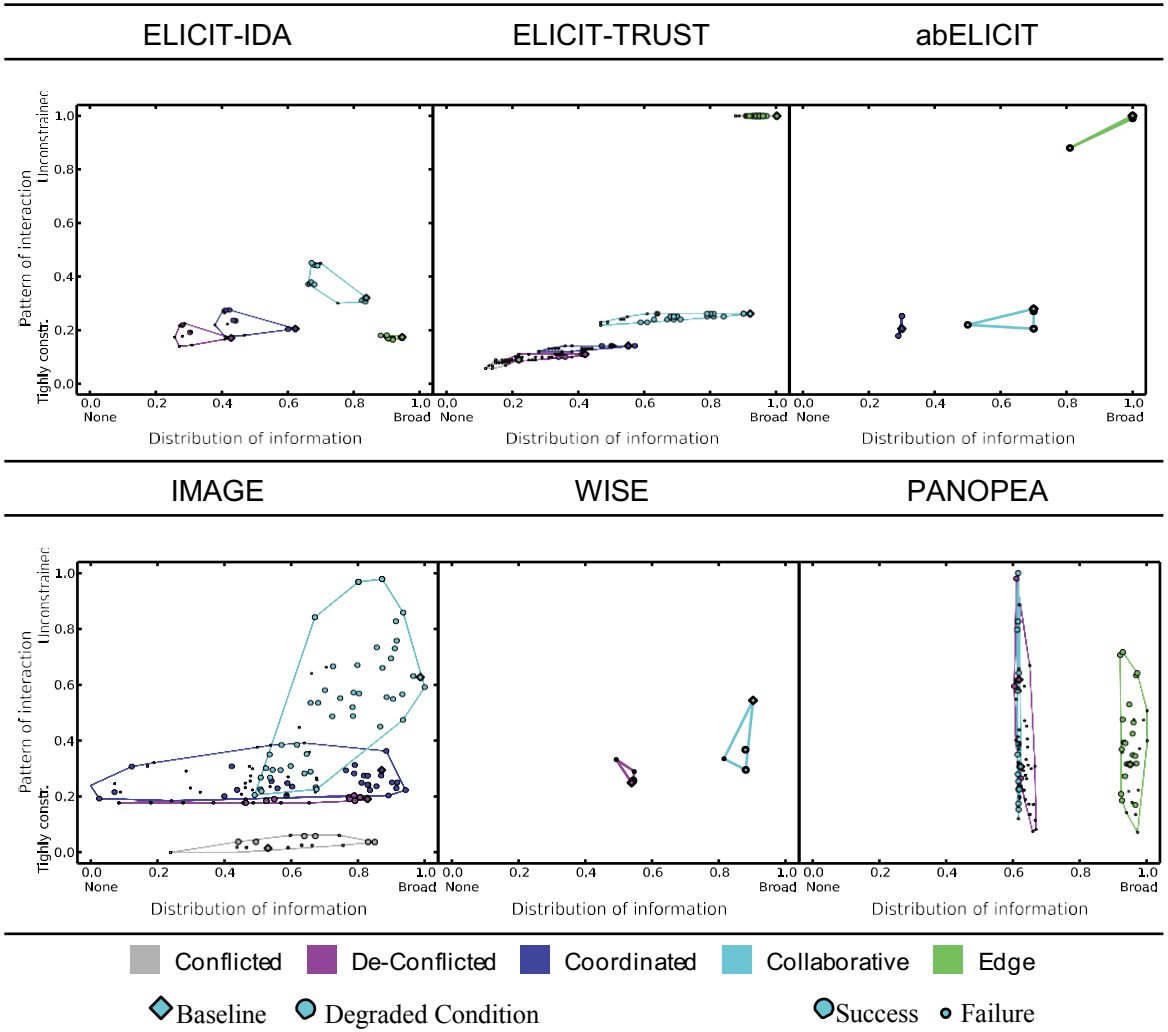
H6: More network-enabled C2 approaches are better able to maintain their position in the C2 Approach Space

- 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



Location Variations in C2 Approach Space

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



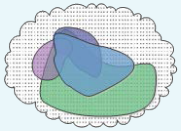
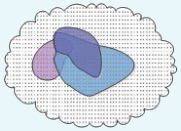
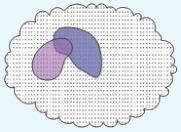
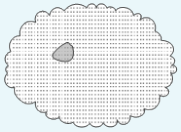
On vs. Off Diagonal

H7: On-diagonal (balanced) approaches to C2 are more agile

C2 Approach	On-Diagonal Group	Off-Diagonal Group
Average % Maximum Effectiveness	82%	36%
Average Distance from Diagonal	0.02	0.09

C2 Maturity → C2 Agility

H9: More mature C2 capability is more agile than the most agile C2 Approach that can be adopted

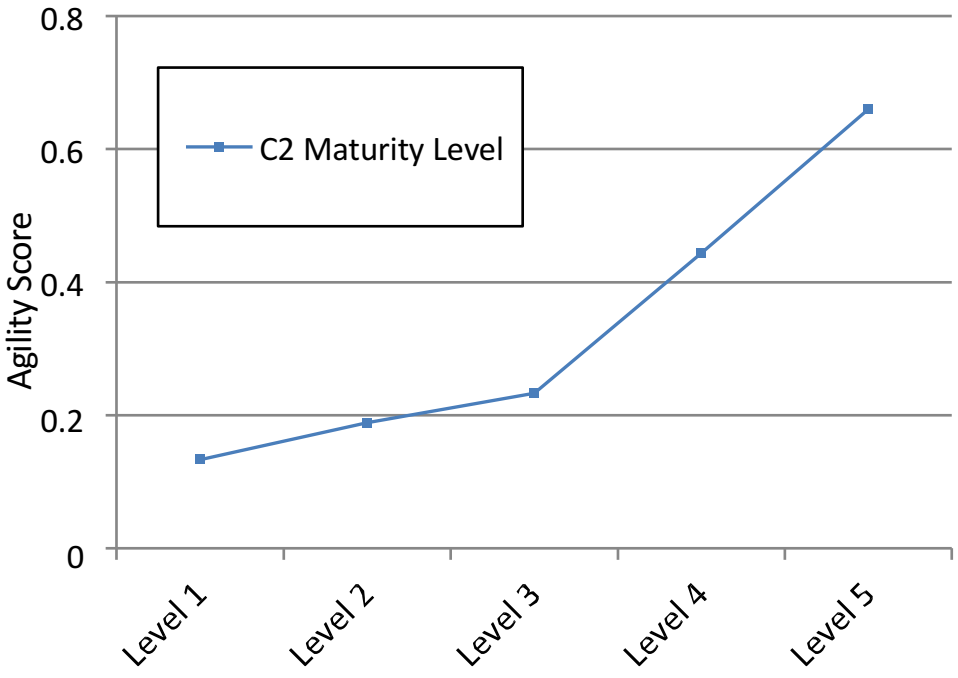
C2 Maturity Levels	Contents of C2 Toolkit	C2 Approach Decision Requirement	Transition Requirements	Region of the Endeavor Space where a collective is successful
Level 5	Edge C2 Collaborative C2 Coordinated C2 De-Conflicted C2	Emergent	Edge C2 Collaborative C2 Coordinated C2 De-Conflicted C2	
Level 4	Collaborative C2 Coordinated C2 De-Conflicted C2	Recognize 3 situations and match to appropriate C2 approach	Collaborative C2 Coordinated C2 De-Conflicted C2	
Level 3	Coordinated C2 De-Conflicted C2	Recognize 2 situations and match to appropriate C2 approach	Coordinated C2 De-Conflicted C2	
Level 2	De-Conflicted C2	N/A	None	
Level 1	Conflicted C2	N/A	None	

Adapted from the Alberts, D.S. (2011). Agility Advantage, CCRP

Conflicted De-Conflicted Coordinated Collaborative Edge

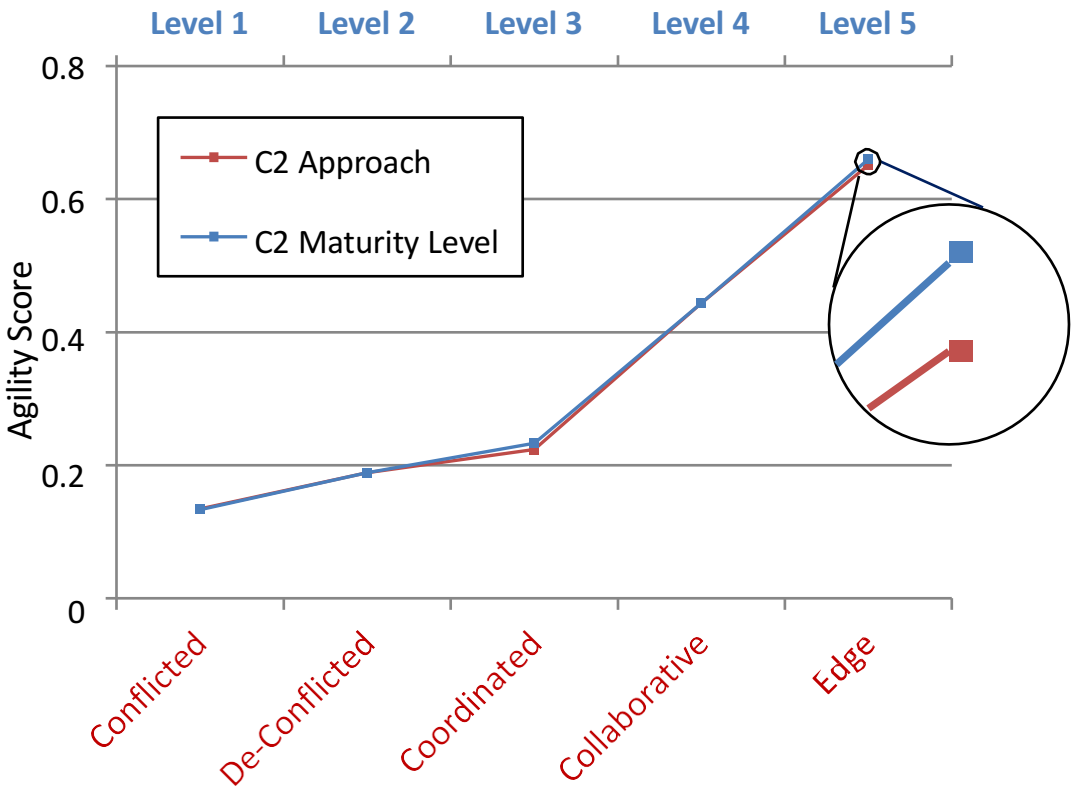
C2 Maturity → C2 Agility

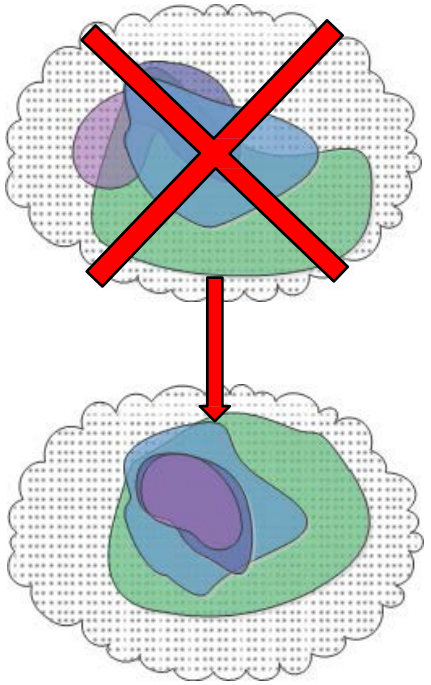
H9: More mature C2 capability is more agile than the most agile C2 Approach that can be adopted



C2 Maturity → C2 Agility

Experimental results suggest more an imbricated model than a complementary one





Summary of Experimental Findings

Hypothesis	Results sustain the hypothesis?	Amount of evidences
H1: Each of the NATO C2 Maturity Model approaches (i.e., Conflicted, De-Conflicted, Co-ordinated, Collaborative, and Edge) is located in a distinct region of the C2 Approach Space	Yes	High
H2: No one C2 Approach to C2 is always to most appropriate	Yes	Medium
H3: More network-enabled Approaches to C2 are more appropriate for more challenging mission/circumstances, however less network-enabled C2 Approaches to C2 are more appropriate for some missions/circumstances	Yes	Medium
H4: More network-enabled approaches to C2 are more agile	Yes	High
H5: The dimensions of the C2 Approach Space are positively correlated with agility	Yes (2 out of 3)	Medium-High
H6: More network-enabled C2 Approaches are better able to maintain their position in the C2 Approach Space	No	None
H7: On-diagonal (balanced) approaches to C2 are more agile	Yes (ELICIT-IDA)	Low
H9: More mature C2 capability is more agile than the most agile C2 Approach that can be adopted	Yes	Low

Agenda

- Objectives
- Basics of Agility
- C2 Agility
- C2 Agility Hypotheses
- Validation Approach
- Campaign of Experimentation
- Summary of Findings, Conclusions, and Way Ahead

General Findings

- We are confident the theory is sound and ready to be tested in the field
- Increased C2 Agility improves the likelihood of mission success in the cases studied and the experiments conducted
- An Entity's C2 Agility can be improved by being able to adopt more approaches
- The extent to which C2 Agility is required is a function of the complexity and dynamics of the set of potential mission challenges faced (Endeavour Space)
- The set of concepts we call C2 Agility are understandable
- C2 Agility and the key variables associated with it can be observed and measured in both experimental and real world settings

“So Whats” from Hypotheses (1)

- There is more than one approach to C2. Therefore, Commanders need to become aware of this fact and recognize how C2 is being approached (their position in the C2 Approach Space).
- Commanders should not assume that their current approach will always work.
- If an entity anticipates being involved in Complex Endeavors, then it should be prepared to adopt more network-enabled approaches.
- If one can only adopt a single approach to C2, then an entity should adopt the most network-enabled approach it can.

"So Whats" from Hypotheses (2)

- All operations are subjected to stresses that can impact C2-related behaviors. This result re-enforces the need for self-monitoring found in the case studies, so that Entities remain aware of where they are located in the C2 Approach Space and how their positions may be affected by stresses.
- There is a need to maintain balance between and among the dimensions of the C2 Approach Space.
- Entities need to not only think about how to select and adopt an approach to C2 but also how to transition from one approach to another.

Future Research

- We need more experimentation and analysis to mature the theory and move from theory to practice
  - We encourage others to replicate our case studies and experiments using their own environments and mission challenges
  - We invite interest parties to join the NATO SAS follow-on activities
- We need to develop a way of visualizing how an organization is functioning so we can quickly ascertain where one is located in the C2 approach Space
- We need to more work on observing the presence or absence of the enablers and their impact on outcomes.