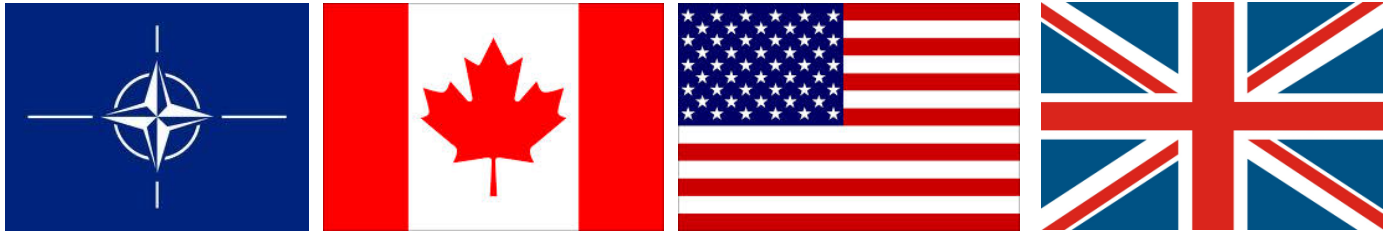

Paper ID: 066

Coping with Degraded or Denied Environments in the C2 Approach Space

François Bernier, Defence R&D Canada, Canada
Kevin Chan, US Army Research Laboratory (ARL), U.S.A.
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Paul Pearce, Defence Science and Technology Laboratory (DSTL), U.K.

18th ICCRTS
C2 in Underdeveloped, Degraded and Denied Operational Environments
June 19-21, 2013 - IDA – Alexandria, Virginia, U.S.A.

Outline

- C2 Agility
- C2 Approach Space and Endeavour Space
- SAS-085 Campaign of Experimentation
- Results on C2 Approach Agility
- Results on C2 Manoeuver Agility
- Summary

Background

- Military missions are now characterized by uncertainty and include a wider spectrum of challenges than in the past
- These Complex Endeavors present a level of difficulty that is qualitatively different from traditional missions
- Previous C2 research and experience indicate that
  - the logical response to high degrees of uncertainty and complexity is to improve agility
  - effectiveness of a Complex Endeavor depends upon the appropriateness of the C2 Approach employed by the Collective

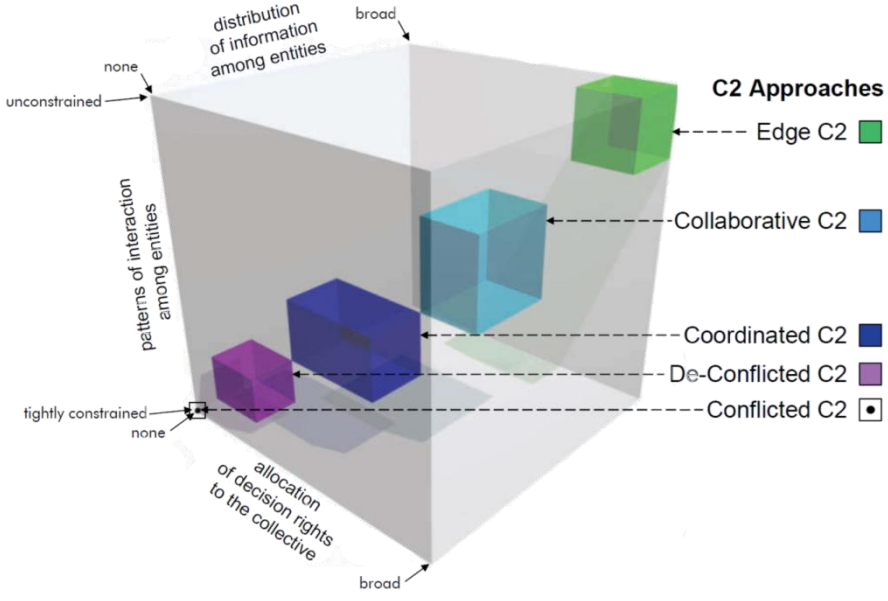
SAS-085 C2 Agility and Requisite Maturity

- SAS-085 on C2 Agility and Requisite Maturity aims to explore the concept of C2 Agility and provide answers to the following questions:
  - What do we mean by Agility / C2 Agility?
  - How can one measure Agility / C2 Agility?
  - To what extent is C2 Agility a requirement for Complex Endeavors / Enterprises?
  - What are the enablers / inhibitors of C2 Agility?
  - Are more networked enabled approaches to C2 more agile?
  - How can one move C2 Agility from a theory to become an institutionalized practice?

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

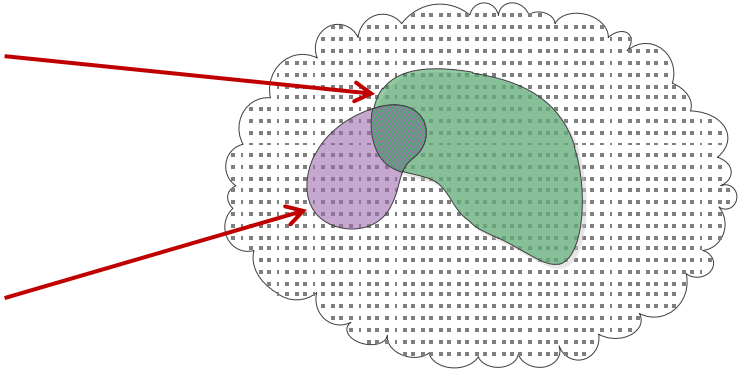
C2 Approach Space and Endeavour Space

C2 Approach Space



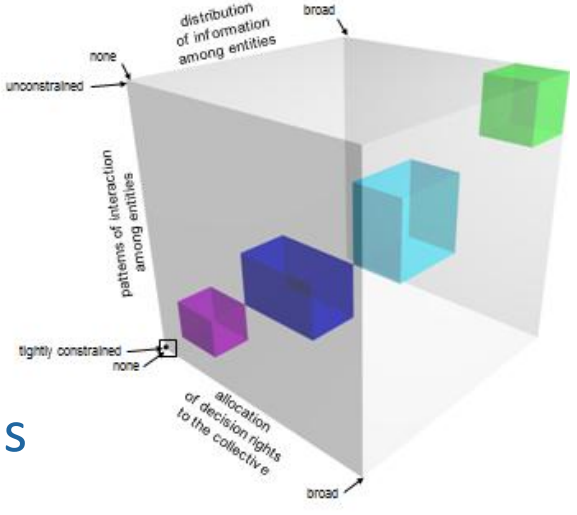
Source: NATO NEC C2 Maturity Model

Endeavor Space



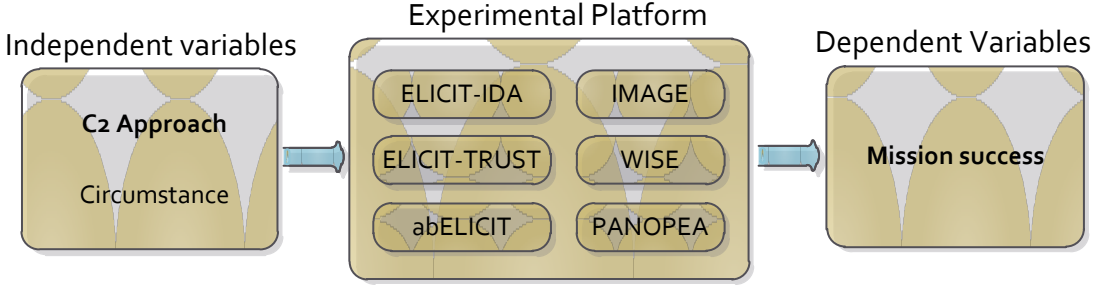
Intended vs. Actual location in the C2 Approach Space

- SAS-085 observed that one needs to make a distinction between the designed C2 operating point (the intended C2 Approach) and the actual operating point in the C2 Approach Space
- Degraded and Denied environment may impact negatively such location (e.g. the actual flows of information can be adversely affected by a circumstance like a network outage)
- By comparing the actual to the intended positions we can determine if a collective is able to maintain its intended position within the C2 Approach Space



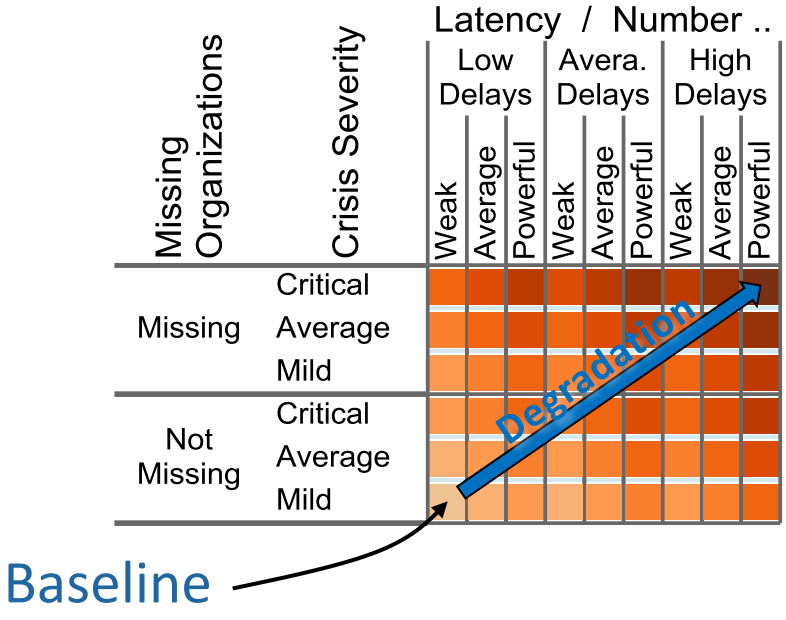
SAS-085 Campaign of Experimentation

- SAS-085 undertook a meta-analysis based on a common high-level experimentation design utilizing multiple experimental platforms
- The campaign showed that more network-enabled C2 Approaches are more agile
- Possible origins of agility were investigated with three hypotheses
  - Entities operating in more network-enabled C2 Approaches can maintain a better
    - H1.1 relative location (relative to the non-degraded condition) in the C2 Approach Space
    - H1.2 global location in the C2 Approach Space
  - H2: The position in the C2 Approach Space is positively correlated with agility



Endeavour Space and Degraded Conditions

- Each Endeavour Space was populated by one baseline and from 3 to 107 degraded conditions
- Darker shades of orange represent the higher levels of degradation



$$Endeavour\ Space = \sum Circumstances$$

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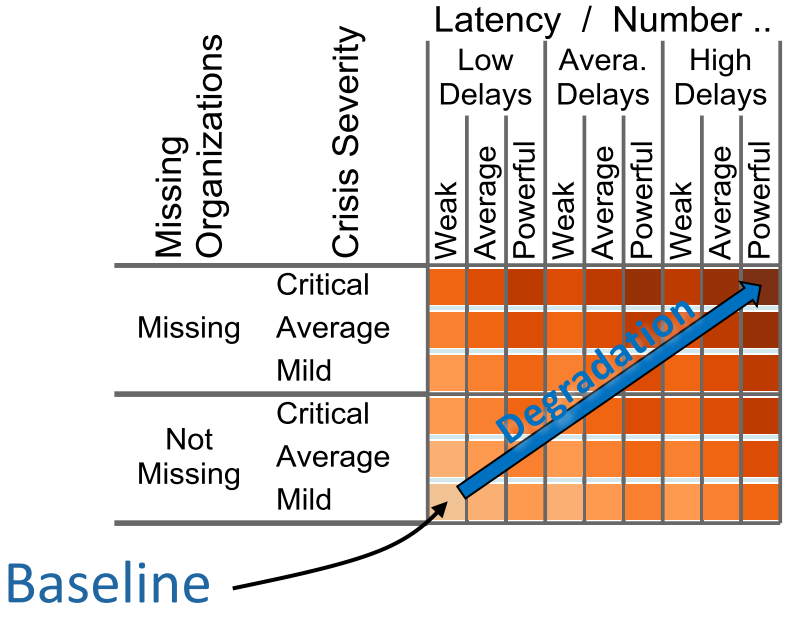

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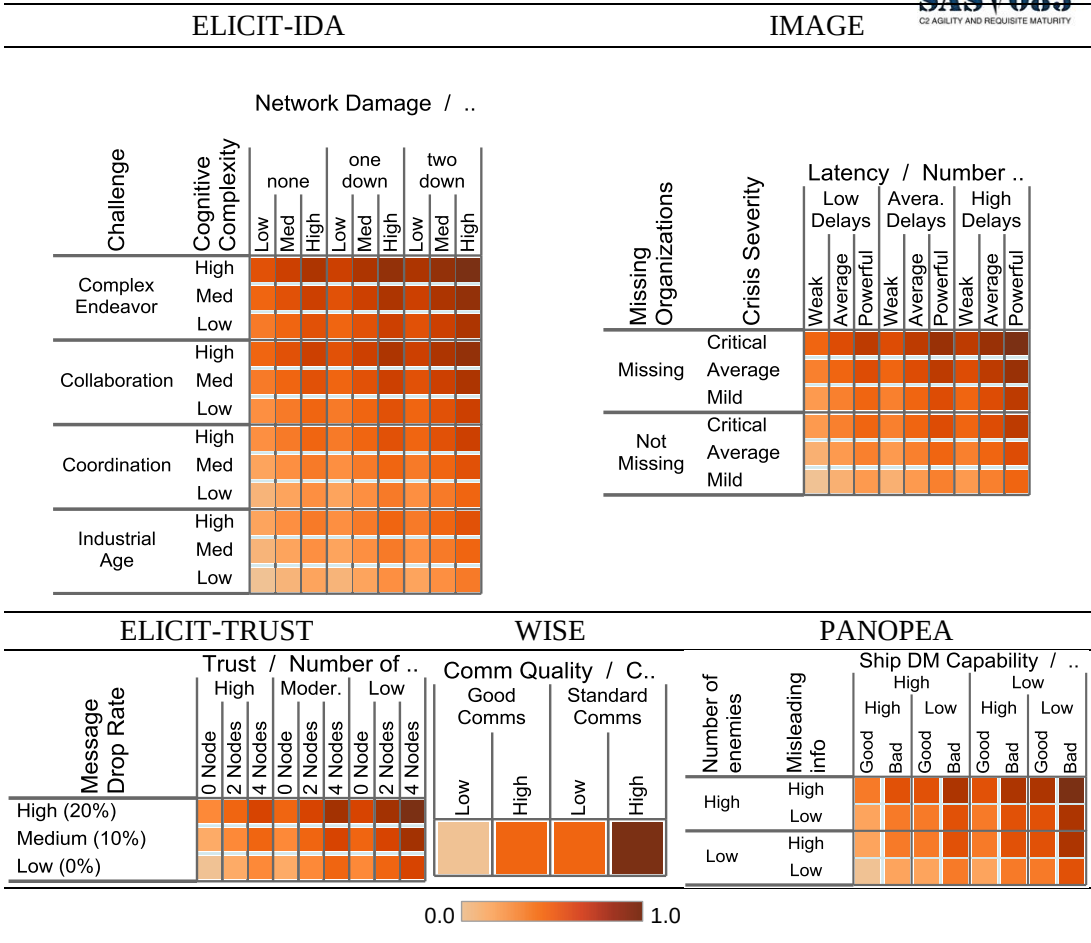
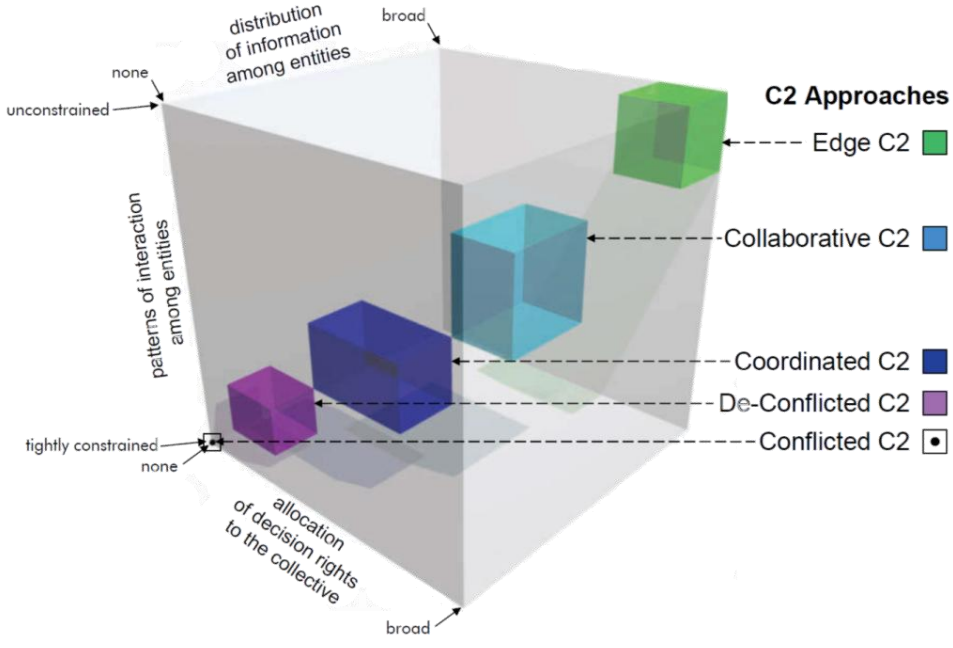
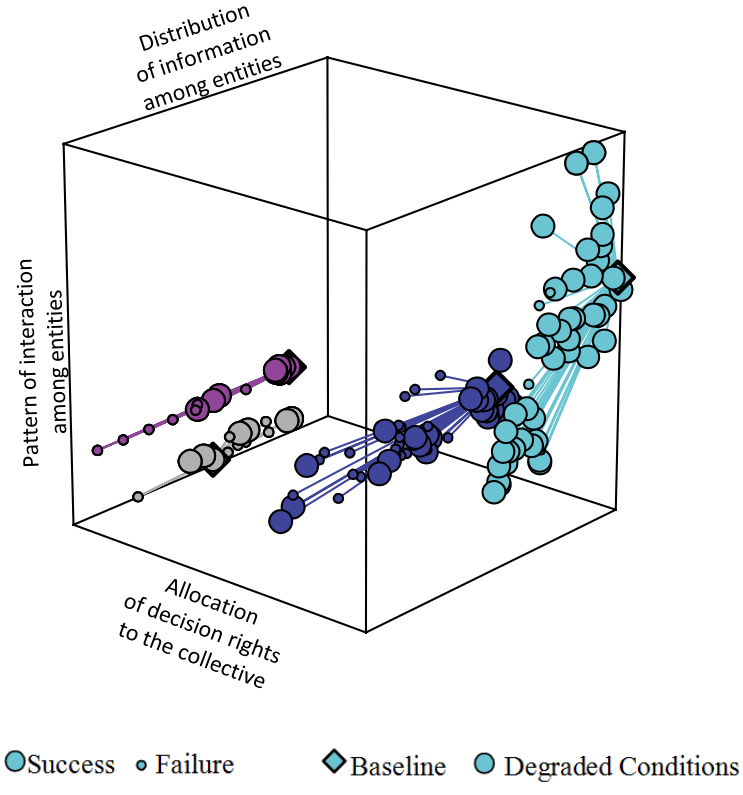


3D Mapping of the Endeavour Space into the C2 Approach Space

Theoretical Locations



Measured/Experimental Locations (IMAGE)



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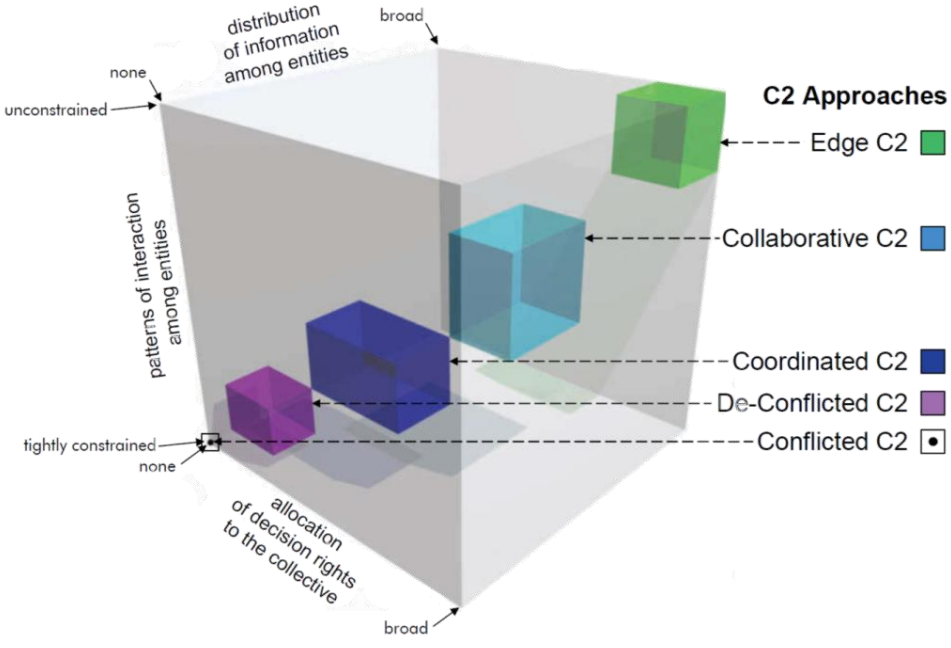

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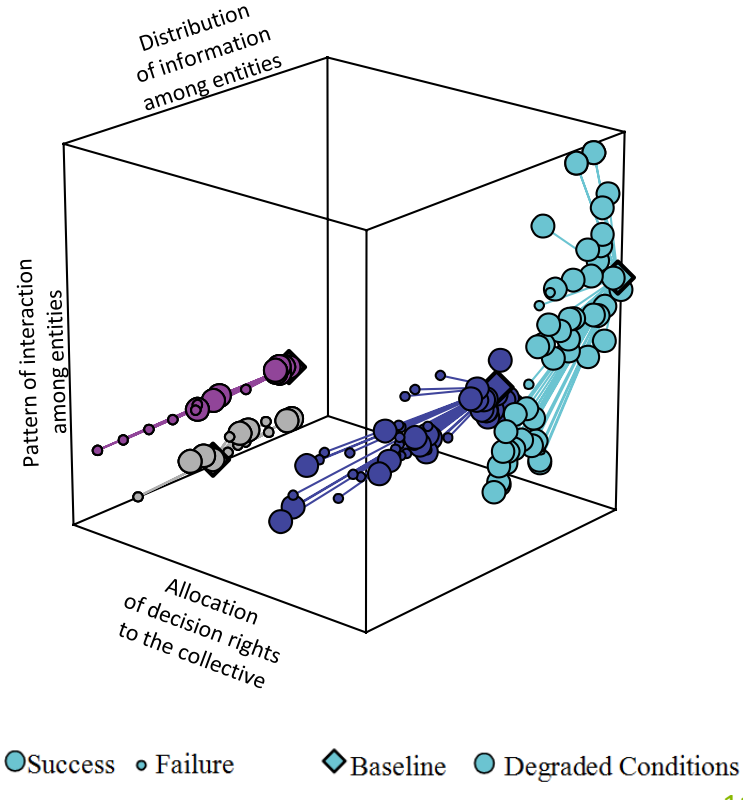

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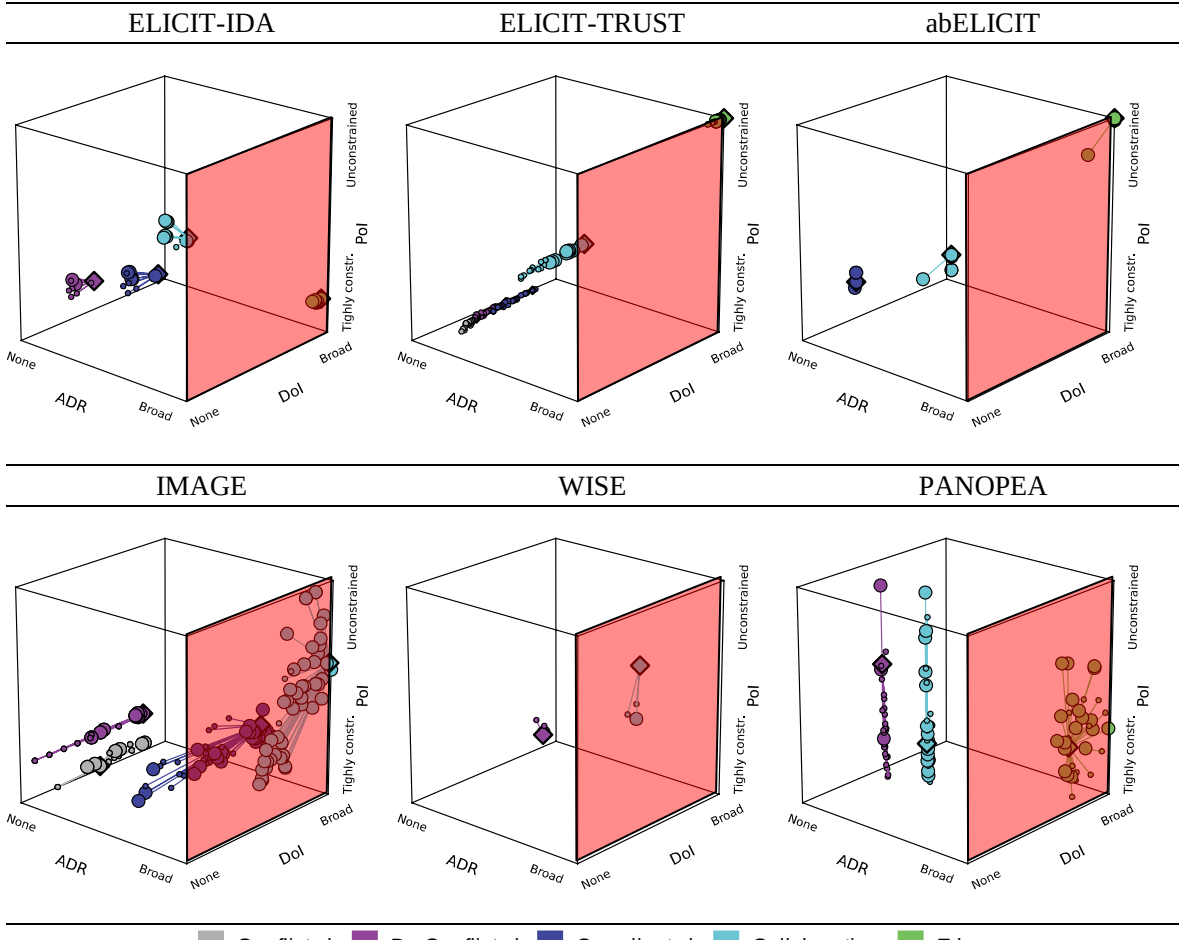
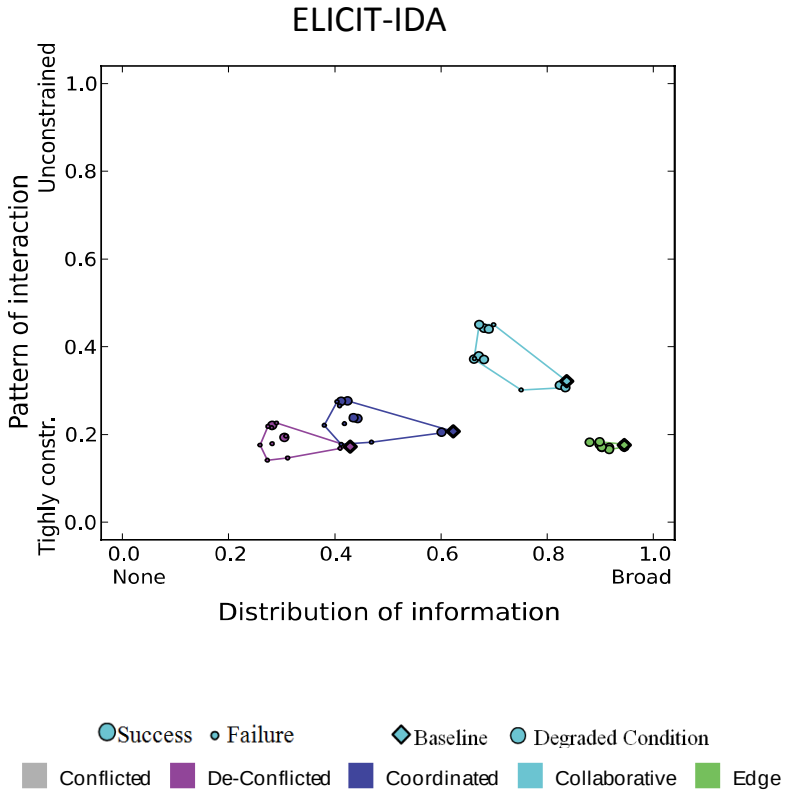


ADR : Allocation of Decision Rights PoI: Patterns of Interaction DoI: Distribution of Information

H1.1: Maintaining its Relative 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
- There was no effect for *C2 Approach* on the calculated areas [$F(4,11) = 0.81$, $p = .54$]



Note: This is a two-dimensional projection of the previous 3D graphics

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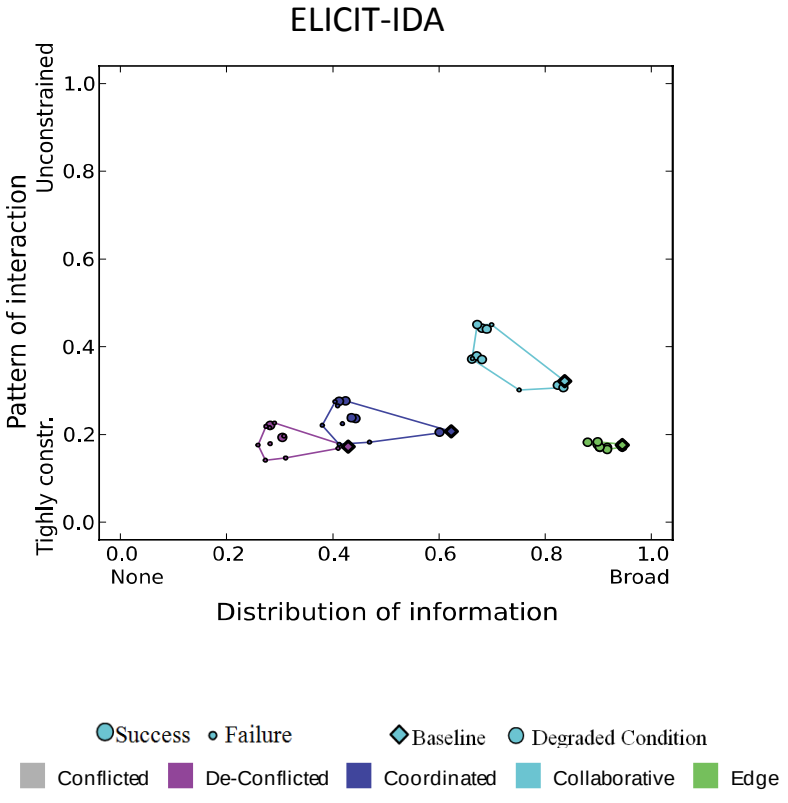

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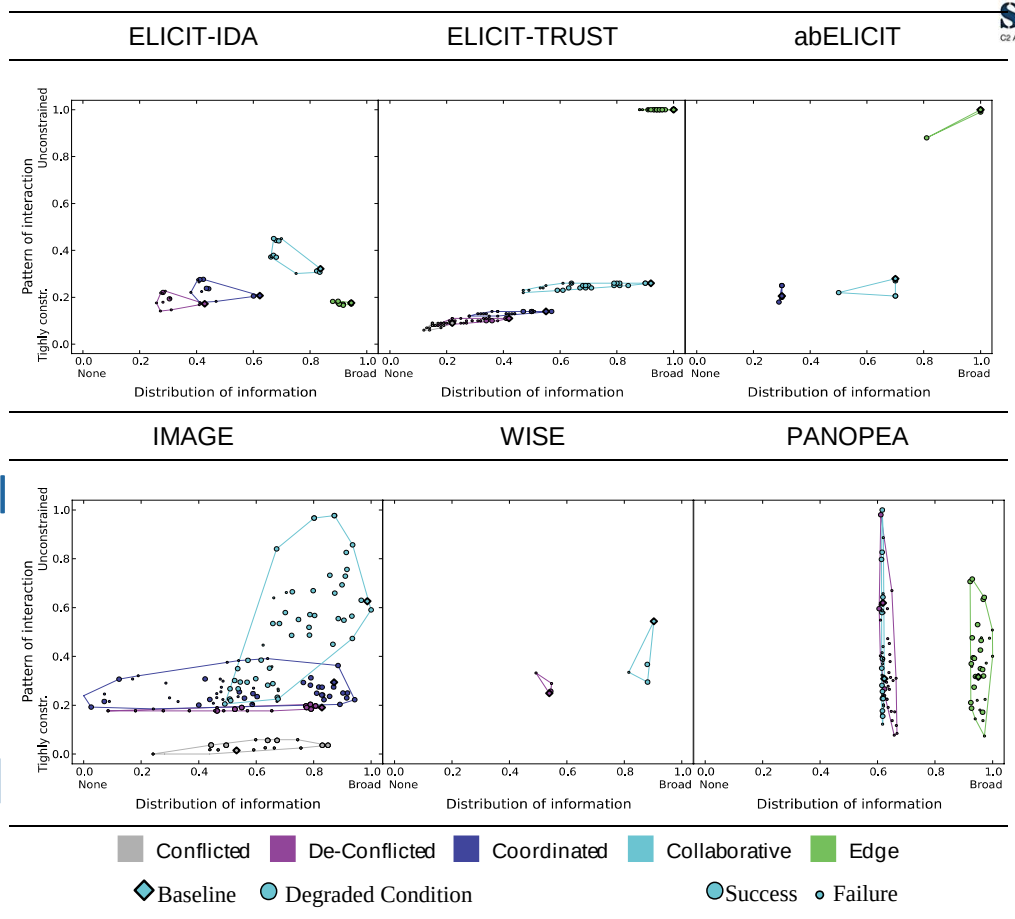
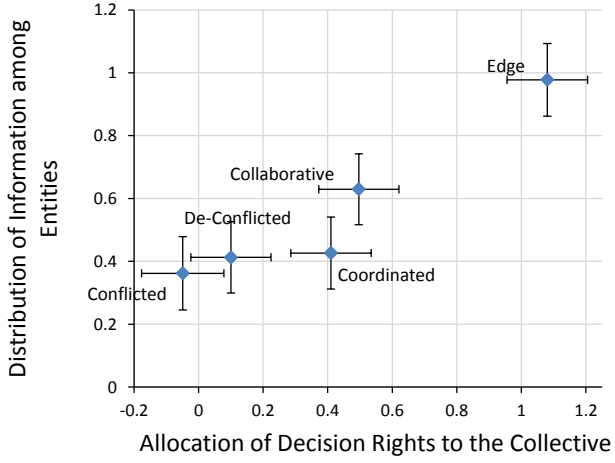
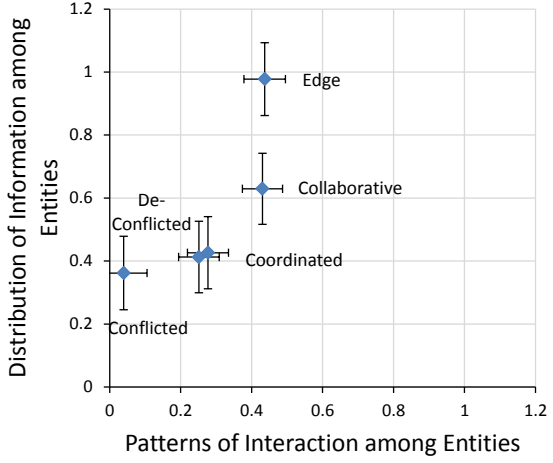


Note: This is a two-dimensional projection of the previous 3D graphics

H1.2: Absolute Position in the C2 Approach Space

- There was a significant effect for *C2 Approach* on the position for each of the dimensions of the C2 Approach Space (error bars = 0.95 confidence intervals)

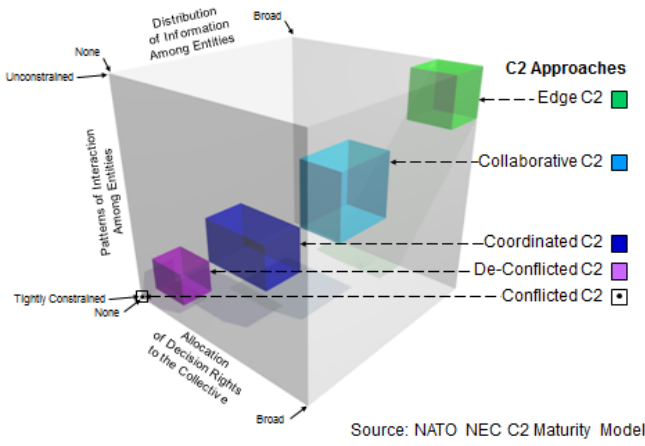




- Post hoc comparisons performed with Tukey's test reveal that 25 out of 30 pairs of comparisons are significant (83%). Non significant comparisons include
  - three pairs for distribution of information (Conflicted vs. Coordinated, Conflicted vs. De-Conflicted, and De-Conflicted vs. Coordinated)
  - two pairs for patterns of interaction (De-Conflicted vs. Coordinated and Collaborative vs. Edge)
- The C2 Approaches are located in distinct regions of the C2 Approach Space in spite of adverse events or degraded conditions

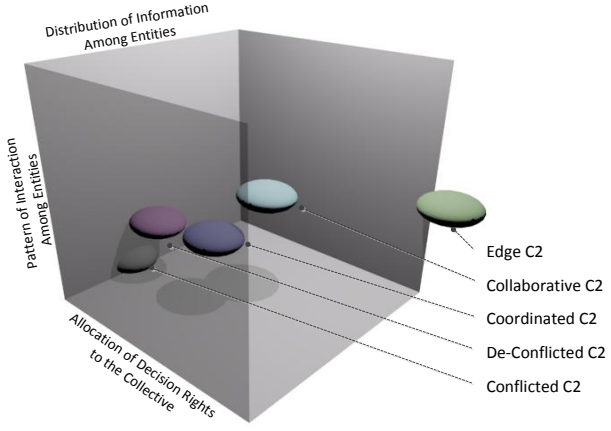
H1.2: Absolute Position in the C2 Approach Space

Theoretical Locations



Source: NATO NEC C2 Maturity Model

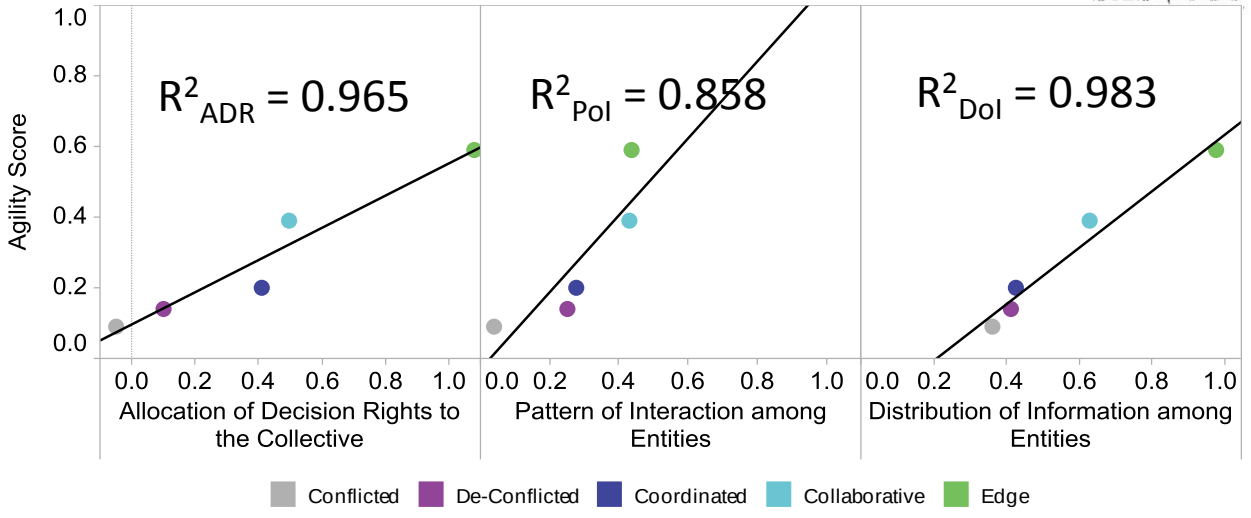
Measured/Experimental Locations



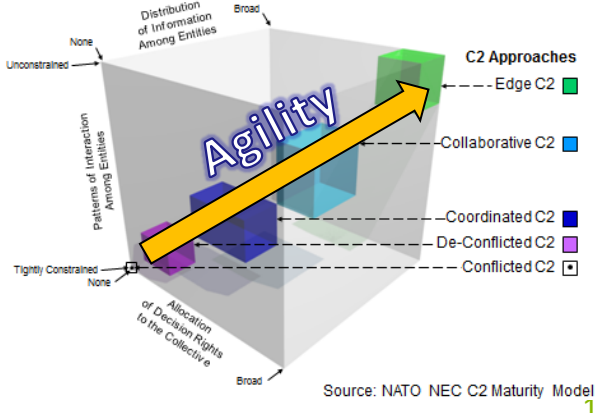
- Locations of the C2 Approaches in N2C2M2 theoretical model were never intended as a strict definition as to the location of each C2 Approach
- Surprisingly, experimental data comply largely with the N2C2M2 theoretical model
- Notable differences are for Conflicted and Edge

H2: Correlation Between C2 Approach Space and Agility

Agility Score represents proportion of the endeavor space (baseline + degraded condition) in which a collective is successful



- Agility Score is strongly correlated to each dimension of the C2 Approach Space (taken separately)
- Thus, being located closer to the Edge corner is associated with more agility



Source: NATO NEC C2 Maturity Model

H2: Correlation Between C2 Approach Space and Agility

- A multiple linear regression analysis was conducted based on three predictors (each dimension of the C2 Approach Space) to see how it predicts Agility Score

Dimension (Predictor)	β	t(14)	P*
Allocation of decision rights	0.460	2.75	0.01
Patterns of interaction	-0.269	1.26	0.22
Distribution of information	0.274	1.26	0.22

*note: $p < 0.25$ which is considered as valid in multiple regression analysis

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

- The result of the linear regression indicates that the dimensions of the C2 Approach Space explain 51% of the variance of Agility Score (Adjusted $R^2 = .51$, $F(3,18) = 8.37$, $p = .001$)
- An polynomial (quadratic) regression indicates that the dimensions of the C2 Approach Space explain 71% of the variance of Agility Score (Adjusted $R^2 = .71$, $F(6,16) = 20.82$, $p = .001$)

Summary

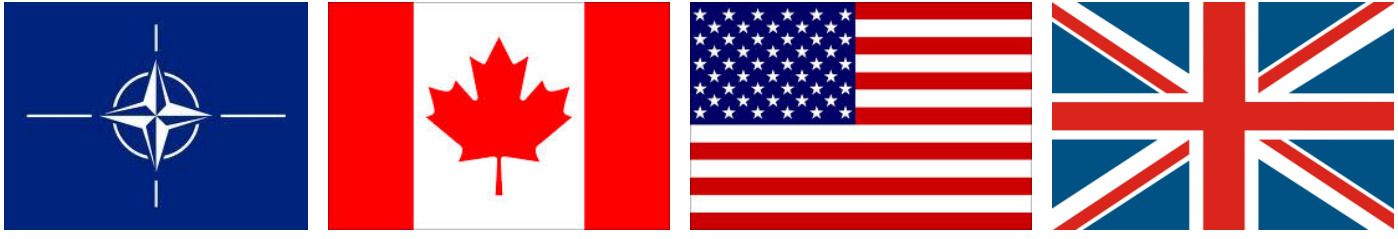
- SAS-085 Campaign of Experimentation provided a powerful means for exploring and validating concepts of agility and C2

H1.1: Entities operating in more network-enabled C2 Approaches can maintain a better relative location (relative to the non-degraded condition) in the C2 Approach Space	✗
H1.2: Entities operating in more network-enabled C2 Approaches can maintain a better global location in the C2 Approach Space	✓
H2: The position in the C2 Approach Space is positively correlated with agility.	✓

- Three other papers (#015, #034, #048) on this experiment are presented in this conference

SAS 085

C2 AGILITY AND REQUISITE MATURITY



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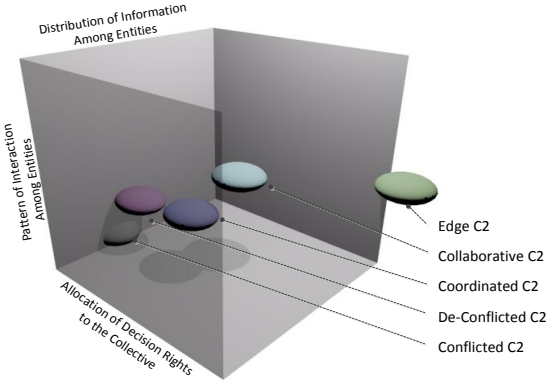
SCIENCE, TECHNOLOGIE ET SAVOIR POUR LA DÉFENSE ET LA SÉCURITÉ DU CANADA

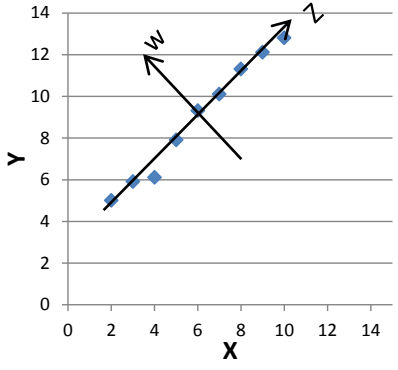
ARL IDA [dstl]

H1.2: Absolute Position in the C2 Approach Space

- The entire volume of the C2 Approach Space is not occupied and locations tend to be distributed along the diagonal
- Do we really need three dimensions?
- A Principal Component Analysis (PCA) was conducted on the location in the C2 Approach Space in order to identify the optimal transformation of axes



Fictional example

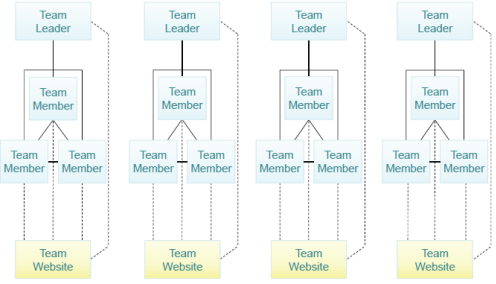


Z accounts for 99.7% of the variability

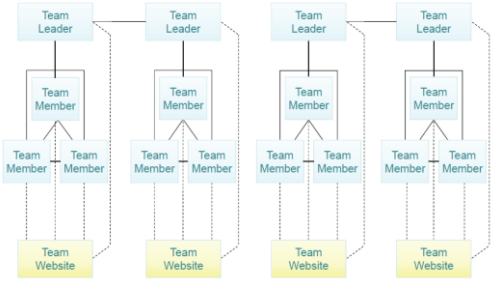
- The first dimension accounts for 82.0% of the variance, the second for 10.6% and the last one only for 7.4% when the analysis is conducted on the average location
- This means that the C2 Approach Space is at 93% a C2 Approach Plane

Scenario - ELICIT

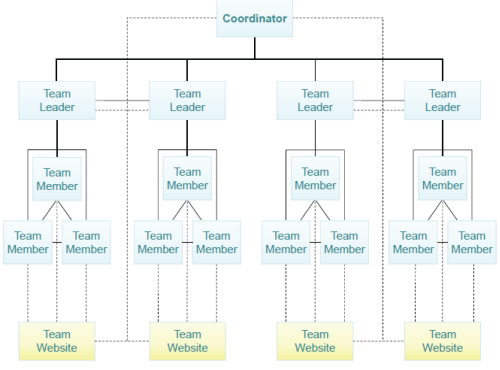
Conflicted



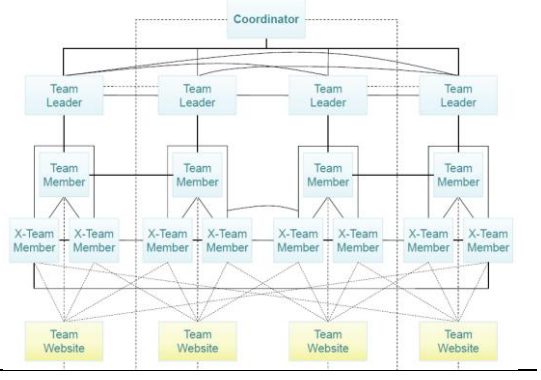
De-Conflicted



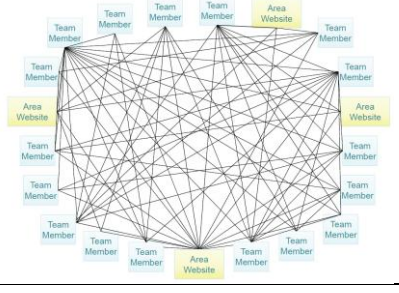
Coordinated



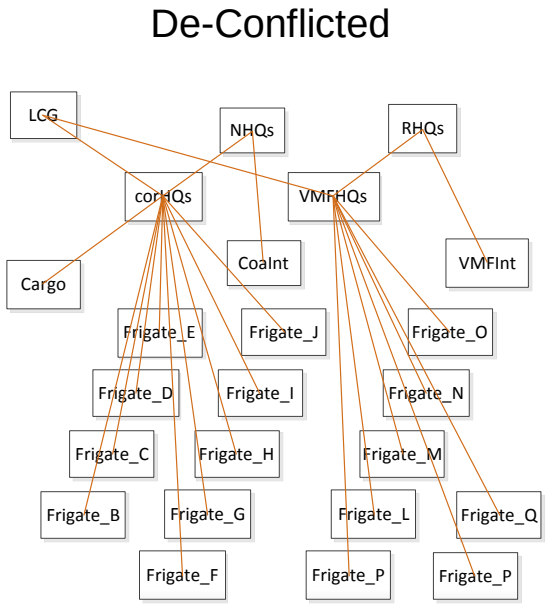
Collaborative

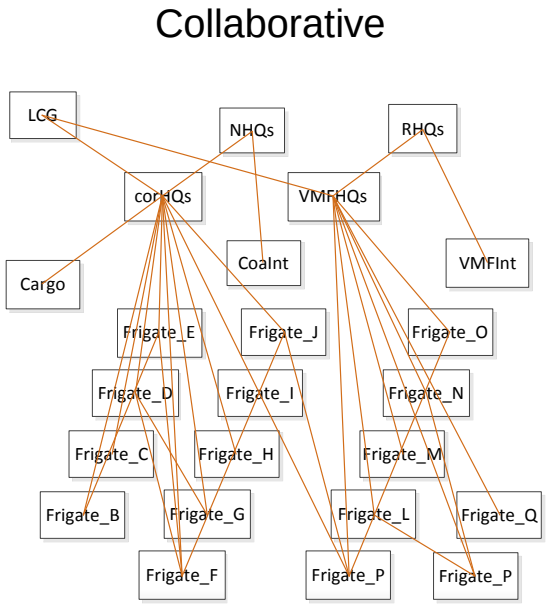


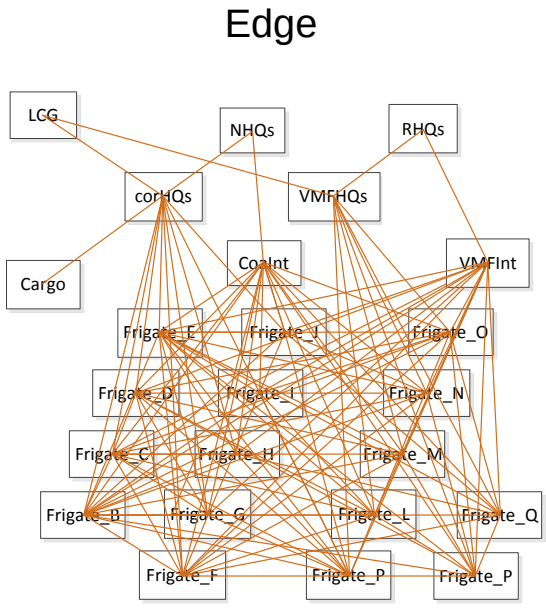
Edge



Scenario - PANOPEA







Scenario - IMAGE

C2 Approach	ADR	PoI	DoI	Planning process
Conflicted	Each organization decides of its unit locations and activities	Between units of the same organization	Between units of the same organization	Move units(s) to most problematic province(s) and then select the activity for each unmoved unit that impacts the variable with the lowest value
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	Like in *conflicted* but conflicting activities are not allowed
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)	Like in *conflicted* but all possible interactions between activities with collocated units are considered
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.)	All combinations of unit locations and activities are considered; those with the higher impact are retained.