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STO TECHNICAL REPORT **STO-TR-SAS-085**

C2 Agility

Task Group SAS-085 Final Report

SAS-085 Final Report on C2 Agility

Executive Summary

Agility is the capability to successfully effect, cope with, and/or exploit changes in circumstances. While other factors will also influence outcomes, C2 Agility enables entities to effectively and efficiently employ the resources they have in a timely manner in a variety of missions and circumstances. SAS-085 was formed to improve the understanding of C2 Agility and assess its importance to NATO. SAS-085 accomplished these objectives by articulating the principles of C2 Agility, in the form of a C2 Agility Conceptual Model, substantially validating this model and establishing the importance of improving C2 Agility with empirical evidence obtained from a set of retrospective case studies and simulation-based experiments. Further, it identified next steps toward practical implementation in NATO operations and priorities for increasing the rigor and practicality of methods for measuring and improving C2 Agility.

The 21st century military mission space is large and complex, characterized by extreme uncertainty, and exposed to increased public and media scrutiny. In addition to the high intensity combat operations traditionally associated with the military, potential missions include a wide spectrum of challenges such as counter-insurgency, counter-terrorism, stabilization, reconstruction, and support to multi-agency disaster relief. These missions are referred to as complex endeavors and require the participation and contributions of a large variety of both military and non-military actors.

The core tenets of C2 Agility are:

- Given the differences between and among these mission challenges and the collections of entities needed to meet them, different approaches to C2 are required.
- There will also be times when an entity is engaged in a highly dynamic situation where the mission, and/or the circumstances will change and one's current C2 Approach will no longer be appropriate.
- Thus, entities also need to be able to dynamically transition from their current C2 Approach to a more appropriate one; that is, to maneuver in the C2 Approach Space.
- This ability to maneuver in the C2 Approach Space involves: 1) recognizing the significance of changes in circumstances that affect the appropriateness of one's C2 Approach, 2) understanding which C2 Approach(es), given the new mission and/or circumstances, are now more appropriate, and,3) being able to transition, as necessary, to a more appropriate approach.

Based on its retrospective case studies and simulation-based experiments, SAS-085 concluded that:

- C2 Agility is a critical capability that should be pursued with some urgency by NATO and its member nations, and
- C2 Agility Theory has matured to the point where it can support practical efforts to improve C2 Agility.

Abstract

Agility is the capability to successfully effect, cope with, and/or exploit changes in circumstances. While other factors will also influence outcomes, C2 Agility enables entities to effectively and efficiently employ the resources they have in a timely manner in a variety of missions and circumstances. SAS-085 was formed to improve the understanding of C2 Agility and assess its importance to NATO. SAS-085 accomplished these objectives by articulating the principles of C2 Agility, in the form of a C2 Agility Conceptual Model, substantially validating this model and establishing the importance of improving C2 Agility with empirical evidence obtained from a set of retrospective case studies and simulation-based experiments. Further, it identified next steps toward practical implementation in NATO operations and priorities for increasing the rigor and practicality of methods for measuring and improving C2 Agility.

Keywords

Command and Control (C2), Agility, Organization, C2 Approach, Responsiveness, Adaptiveness, Flexibility, Resilience, Innovation, Versatility, Complex Endeavors, Complex Enterprises, Modeling and Simulation, Experimentation, Case Studies, Measures of Effectiveness, Experiments, Campaign of Experiments, Meta-Analysis, Agility Maps, Heterogeneous C2, C2 Maneuver, C2 Approach Space, Endeavors Space, Mission Command, Agile C2

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SAS-085 would not have been possible but for the existence of a considerable body of C2 research, developed over several decades, that includes significant contributions by previous NATO research groups, specifically SAS-026 that developed a code of Best Practice for C2 Assessment, SAS-050 that developed a C2 conceptual reference model, and SAS-065 whose NATO NEC C2 Maturity Model and its conclusions regarding C2 Maturity and Agility inspired this effort. The products they produced and the insights they develop have enabled us to make far more progress than would have been otherwise possible. Furthermore, key members of these NATO groups made themselves available to mentor our efforts. In particular, we would like to thank Professor Emeritus Reiner Huber who has devoted a major part of his professional career to these C2-related NATO groups and served as a senior mentor for this one. SAS-085 was, by any accounts, a major undertaking that required considerable effort on the part of all members. We would like to thank our member Nation's host organizations for their support in arranging for meeting venues. SAS-085 is a research activity undertaken under the auspices of the SAS Panel of the NATO Science and Technology's Collaboration and Support Office. The Panel was instrumental in helping to organize this effort and made key contributions during the course of this research.

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EXECUTIVE OVERVIEW

The NATO Research Task Group, SAS-085, accomplished its objectives by articulating the principles of Command and Control (C2) Agility and substantially validating them with empirical evidence. Further, the group identified next steps toward practical implementation in NATO operations and priorities for increasing the rigor and practicality of methods for measuring and improving C2 Agility.

BACKGROUND

The success of an approach to C2 is determined by its appropriateness, given the nature of the mission and the circumstances, as well as the collection of entities needed to accomplish it. The 21st century military mission space is large and complex, characterized by extreme uncertainty, and exposed to increased public and media scrutiny. In addition to the high intensity combat operations traditionally associated with the military, potential missions include a wide spectrum of challenges such as counter-insurgency, counter-terrorism, stabilization, reconstruction, and support to multi-agency disaster relief. In many of these endeavors, the effects that need to be created involve more than traditional military effects and include inter-related economic, social and political effects. These missions are referred to as *Complex Endeavors* and require the participation and contributions of a large variety of both military and non-military actors, a collective that SAS-085 refers to as a *Complex Enterprise*. Given the differences between and among these mission challenges and the collections of entities needed to meet them, different approaches to C2 are required.

The ongoing transformation of 21st century institutions and actors from the Industrial Age to the Information Age and beyond to an age some call the “Age of Interactions” continues to have a profound effect on how institutions manage themselves, and how they work with others. This can be attributed to increasingly accessible and affordable mobile networking and related trends that are inexorable, creating both vulnerabilities and opportunities that are shaping the information-related capabilities of the various actors and the environment in which these missions take place.

This *‘networked’* reality requires that NATO and its member Nations rethink C2, interpreted in its broadest sense to include acquiring, managing, sharing and exploiting information, and supporting individual and collective decision-making. As our understanding of Complex Endeavors and Complex Enterprises matures, we will be better able to recognize the changes in missions and circumstances that require corresponding changes in the way C2 is approached. The ability to dynamically adopt an appropriate C2 Approach is integral to C2 Agility.

SAS-085

Previous research and experience indicate that the logical response to high degrees of uncertainty and complexity is to improve Agility. Agility, like any other *‘good’,* is not an end unto itself and exhibiting maximum Agility is often not the answer. SAS-085 was formed to improve the understanding of C2 Agility, the variables that it influences, and the variables that, in turn, influence it. SAS-085 has developed a conceptual model of C2 Agility that captures the relevant variables and relationships. A number of agility-related hypotheses are suggested by this model. SAS-085 has conducted both retrospective case studies and simulation-based experiments to validate this model and to test these hypotheses.

THE CONCEPTUAL MODEL OF C2 AGILITY

C2 Agility is the capability of C2 to successfully effect, cope with, and/or exploit changes in circumstances. While other factors will also influence outcomes, C2 Agility enables entities to effectively and efficiently employ the resources they have in a timely manner.

The functions associated with C2 can be accomplished in a wide variety of ways. NATO research group, SAS-050, concluded that C2 Approaches can be categorized by how decision rights are allocated, how entities interact, and how information is distributed.

These form the key dimensions of an entity's[1] C2 Approach Space, as depicted in Figure EO-1: C2 Approach Space.

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

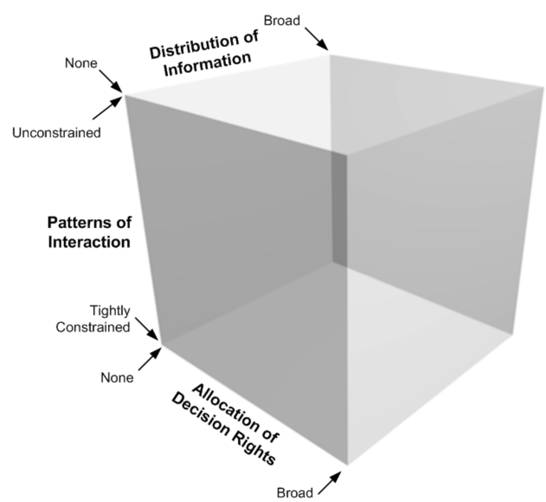

Figure EO- 1: C2 Approach Space

In practice, these dimensions are inter-dependent as, for example, the way decision rights are allocated will have a considerable influence on the patterns of interactions and information flows. Each C2 Approach occupies its own region in the C2 Approach Space.[2] These regions vary from highly centralized, stove-piped hierarchies to loosely-coupled networks.

[1] SAS-085 uses the term "entity" to refer to organizations, teams, individuals, systems, and processes, each of which can manifest agility.

[2] Large organizations and Collectives usually do not employ a uniform C2 Approach. In fact, commanders will give certain subordinates more degrees of freedom than others even if they have similar responsibilities; they will use different C2 Approaches for specific sub missions and tasks. We refer to this phenomenon as C2 Approach heterogeneity. We discuss this later in this report and in more detail in Annex A.

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SAS-065 developed a NATO Network Enabled Capability (NEC) C2 Maturity Model (N2C2M2) that defined five increasingly network-enabled approaches to Collective C2: Conflicted C2, De-Conflicted C2, Coordinated C2, Collaborative C2 and Edge C2 and graphically located them along a diagonal in a Collective's[3] C2 Approach Space as depicted in Figure EO-2: NATO NEC C2 Approaches.

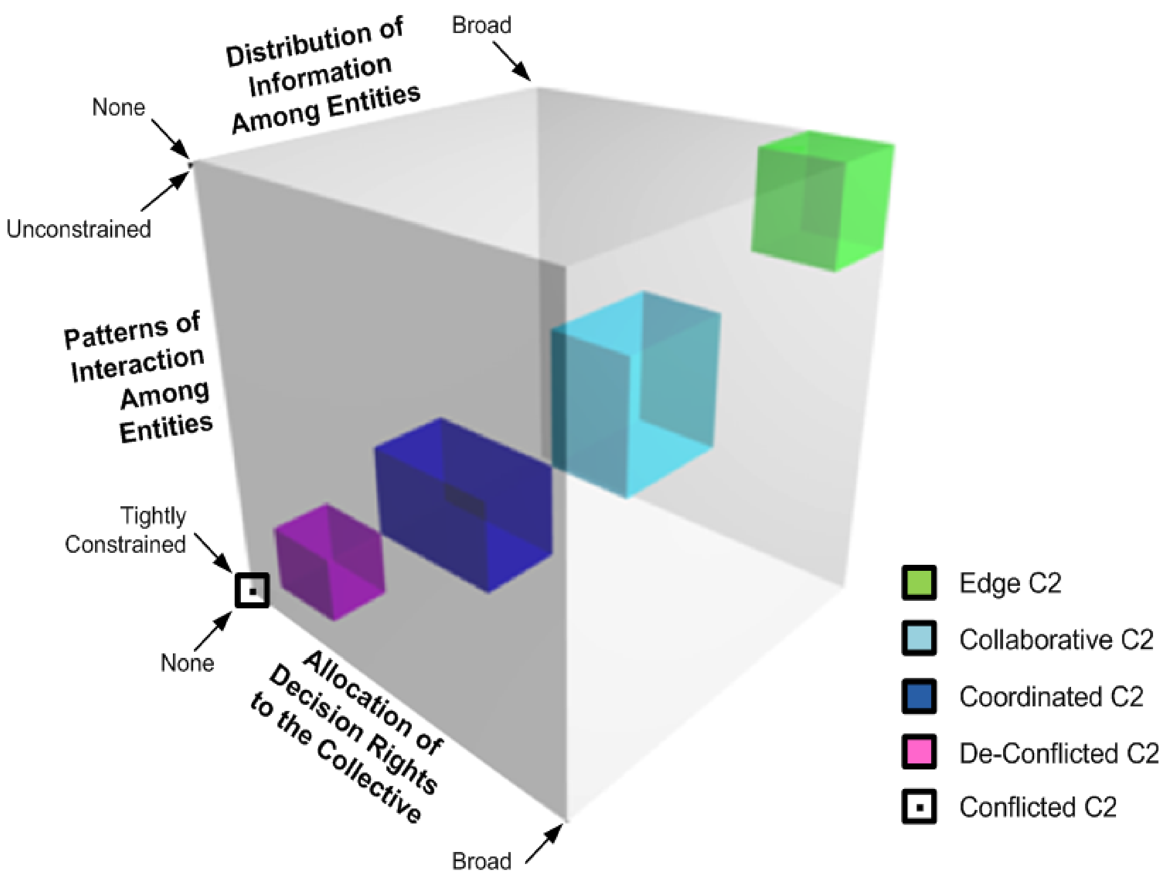


Figure EO- 2: NATO NEC C2 Approaches

A Collective's mission, objectives, and strategy will vary with circumstances and therefore, no single C2 Approach works well for all missions and circumstances. We can visualize an Endeavor Space where different regions correspond to different mission changes.

[3] EO-1 depicts an Entity's C2 Approach Space while EO-2 depicts a Collective's C2 Approach Space. The dimensions differ. For example, the allocation of decision rights are allocated within an entity in the Entity C2 Approach Space and from entities to the Collective in an Collective's C2 Approach Space.

For each region in this Endeavor Space, there is presumably an appropriate C2 Approach, as depicted in Figure EO-3: Appropriate C2 Approach.

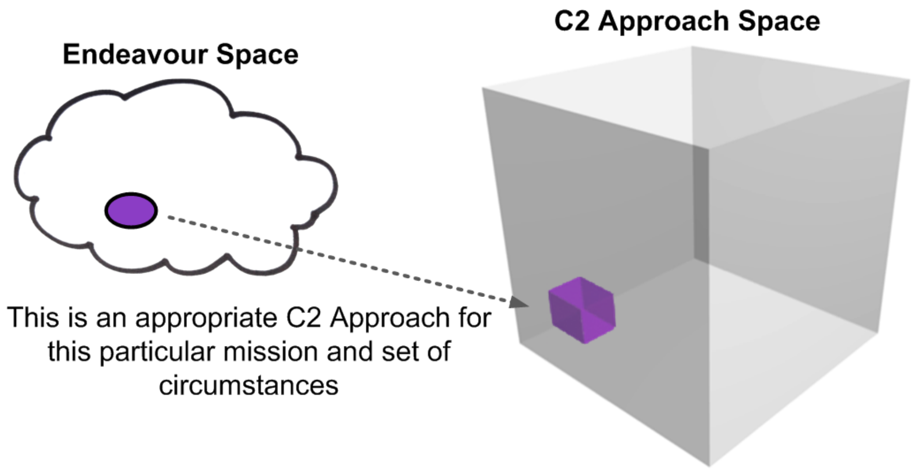


Figure EO-3: Appropriate C2 Approach

As case studies and experiments have shown, entities that carefully consider the nature of the mission and circumstances they face and initially adopt an appropriate C2 Approach increase their likelihood of success. Over time, entities and Collectives may need to be able to successfully operate in many regions in the Endeavour Space. There will also be times when an entity is engaged in a highly dynamic situation where the mission, and/or the circumstances will change and one's current C2 Approach will no longer be appropriate. For both of these reasons then, there is a need to be able to employ more than one approach to C2 to be effective and to remain effective. Thus, entities and Collectives will need to develop the ability to navigate through the C2 Approach Space in response to changing missions and circumstances. This ability to manoeuvre in the C2 Approach Space is necessary for an entity to have if they are to manifest C2 Agility. This ability to maneuver in the C2 Approach Space is depicted in Figure EO-4: C2 Maneuver.

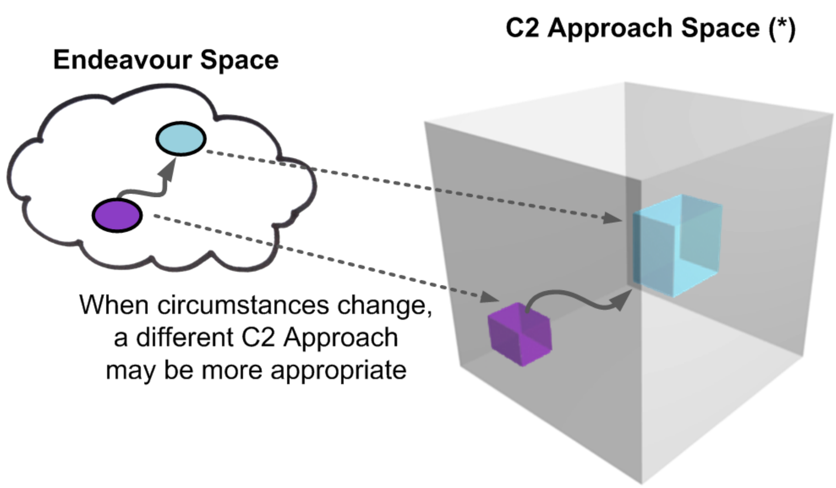


Figure EO-4: C2 Maneuver

C2 Maneuver involves:

1. Recognizing the significance of changes in circumstances that affect the appropriateness of one's C2 Approach,

2. Understanding which C2 Approach(es), given the new mission and/or evolving circumstances, are now more appropriate, and,

3. Being able to transition, as necessary, to a more appropriate C2 Approach.

Therefore, organizations that wish to improve their C2 Agility must monitor not only the external situation but also themselves[4] so that they understand what adjustments in their C2 Approach may be needed to effectively and efficiently maneuver in the C2 Approach Space.

C2 AGILITY HYPOTHESES

The SAS-085 C2 Agility Conceptual Model (C2ACM) suggested a number of testable hypotheses. SAS-085 considered twelve hypotheses that involved the relationship between 1) the actual location[5] of an approach in the C2 Approach Space and its C2 Agility, and 2) C2 Agility and C2 Maneuver. SAS-085 sought to empirically test the clarity and meaningfulness of the C2ACM's basic concepts as well as the validity of these twelve hypotheses using both retrospective case studies and simulation-based experiments.

SAS-085 FINDINGS AND CONCLUSIONS

Based on its retrospective case studies and simulation-based experiments, SAS-085 concluded that:

- C2 Agility is both desirable and feasible

  It is desirable to increase C2 Agility because doing so improves the likelihood of mission success. Increased C2 Agility contributes to mission success by enabling entities to adopt more appropriate approaches to C2 in more situations and to adjust their approaches as the mission and circumstances change. Conversely, a lack of C2 Agility can contribute to a lack of mission success. Improving C2 Agility is feasible because 1) the concepts have proven to be readily understandable, observable and measurable, and 2) key C2 Approach dimensions and other variables that impact C2 Agility can be influenced or controlled by entities.

- C2 Agility Theory has matured to the point where it merits serious consideration by the operational community.

  C2 Agility concepts and practices are ready to be incorporated into education, doctrine, exercises, and, as commanders and staffs learn how to apply these concepts, to be employed. While these concepts

[4] Later in this report we refer to monitoring the state of 'self' and how one is actually operating as *"Self-Monitoring."*

[5] The actual location is determined by observations / calculations of the values of the metrics employed for each of the three dimensions of the C2 Approach Space as opposed to a desired (intended) location

can be applied now, there is much more to understand about alternative approaches to C2, Collective C2, matching missions and circumstances to C2 Approaches, and the benefits and risks associated with both improving C2 Agility and not improving C2 Agility.

- There is no “one-size-fits-all” approach to C2

  Given the variety of missions, circumstances, and the collections of entities needed to meet these varied challenges, there is no single approach to C2 that is appropriate for all of these situations. Therefore, NATO, member Nations, and partners will need to be able to employ more than one approach to C2, understand when different C2 Approaches are appropriate, and have the ability to efficiently transition between and among C2 Approaches in a timely manner.

Taken together these findings and conclusions indicate that the desire expressed by military leaders to improve the Agility of their forces is both well-founded and actionable. SAS-085 members therefore conclude that, given the nature of 21st century mission challenges, C2 Agility is a critical capability that should be pursued with some urgency by NATO and its member Nations.

WAY AHEAD

Having concluded that improving C2 Agility is both desirable and practical, the members of SAS-085 recommend that NATO, member Nations, and partners take the following steps to improve their C2 Agility.

In the short run,

- increase awareness of the need for C2 Agility and the feasibility of improving it
- incorporate C2 Agility concepts into military education and training
- assess the levels of potential C2 Agility in military organizations and their partners
- observe and document C2 Agility when manifested in operations
- organize a community of interest focused on making improvements in C2 Agility

In the mid-term,

- identify specific ways that C2 Agility can be improved
- develop and deploy tools to help organizations improve their C2 Agility
- capture and disseminate lessons learned

As a result of these efforts, it is expected that the longer term will bring substantially greater understanding through an iterative process that involves lessons learned from operations, research, and analysis.

As an integral part of the way ahead, SAS-085 envisions extending the Campaign of Experimentation to address critical path issues, with the following priorities:

- develop *concrete* and practical instantiations of Endeavor Spaces for representative scenarios; test the ability to teach and apply the concepts in specific cases
- develop the characterization of heterogeneous C2 approaches so that related issues can be addressed comprehensibly from the start and effectively reflected in education and training
- improve the definition of agility-related metrics (at different levels of detail) and visualizations, with an eye toward making measurement increasingly down to earth, but solidly rooted
- enrich the mechanisms for analytic experimentation so that they can deal with more stressful aspects of C2 Agility, such as heterogeneity within the Collective and more substantial network problems.

Chapter 1 – INTRODUCTION

"Do better if possible, and that is always possible" *François Constantin, 1819*

"NATO is an active and leading contributor to peace and security on the international stage. Through its crisis management operations, the Alliance demonstrates both its willingness to act as a positive force for change and its capacity to meet the security challenges of the 21st Century. Since its first major peace-support operation in the Balkans in the early 1990s, the tempo and diversity of NATO operations have increased. NATO has been engaged in missions that cover the full spectrum of crisis management operations – from combat and peacekeeping, to training and logistics support, to surveillance and humanitarian relief."[6]
Such 21st Century NATO operations pose twin challenges. The first challenge is borne of the complexities inherent in the diverse set of NATO operations. It has become imperative that we better understand how to operate not only effectively but also efficiently in these highly uncertain and dynamic situations. The second challenge arises from the nature of the enterprise needed to respond to current and future NATO missions, which will continue to include NATO and non-NATO militaries, interagency partners, international organizations, host governments, non-governmental organizations, private industry, and local authorities and leaders. Mission success will depend upon NATO's ability to organize, manage and participate in these heterogeneous enterprises so that their collective capabilities and resources can be effectively and efficiently brought to bear in a timely manner.

The logical response to both these challenges is to increase agility by fashioning more agile approaches to C2 and learning how to choose an approach that is appropriate for the mission, the circumstances and the structure and capabilities of the participating entities.

1.1 SAS-085

SAS-085 was chartered to understand the implications of C2 Agility (or a lack of C2 Agility) for NATO missions and to ascertain the extent to which C2 Agility is worth pursuing as a priority capability for NATO, its member nations, and its partners[7]. This required building upon previous work to define a conceptual model that could:

- Explain what is meant by i) Agility and ii) C2 Agility
- Provide a way to measure both Agility and C2 Agility
- Indicate ways to improve both

[6] http://www.nato.int/cps/en/natolive/topics_52060.htm

[7] SAS-085 (2009) C2 Agility and Requisite Maturity Technical Activity Proposal: Paris: NATO RTO. SAS-085 (2009) C2 Agility and Requisite Maturity Terms of Reference: Paris: NATO RTO.

In an effort to validate this conceptual model and the hypotheses suggested by the model, SAS-085 focused on exploring the following questions:

- To what extent is C2 Agility a requirement for i) Complex Endeavours? and ii) Complex Enterprises?
- What key variables affect C2 Agility, either enabling or inhibiting it?
- Are more networked-enabled approaches to C2 more agile?
- Do entities (e.g. military units, nations, alliances, collectives) need more than one approach to C2?
- What are the costs and risks associated with developing Agility?
- What are the costs and risks associated with NOT developing Agility?
- What is involved in moving C2 Agility from a theory to established practice?

The members of SAS-085 come from 11 countries with representation from NATO Allied Command Transformation and the C2 Centre of Excellence (CoE). A complete list of participants is provided in Annex A.

The final report documents SAS-085's efforts to provide answers to these and related questions. It presents definitions for Agility, C2 Agility and related concepts, provides a conceptual model that identifies key Agility-related variables and their relationships, suggests ways to measure Agility, and identifies critical enablers and impediments. It documents our efforts to validate the conceptual model and test these hypotheses and it concludes with our findings and a suggested way forward.

1.2 REPORT ORGANIZATION

The work of SAS-085 is built upon a considerable body of C2 research, developed over several decades, that includes significant contributions by previous NATO research groups. To enable readers to fully appreciate and understand the concept of C2 Agility and its implications for them and their organizations, this report begins with

Chapter 2. Orientation, a section that explains why business as usual will not enable us to meet some of the mission challenges faced by NATO and its member nations; why Agility is an essential capability; and, provides a synopsis of the conceptual foundation upon which the C2 Agility concepts and theory rests.

Chapter 3. Basics of Agility looks at agility from a broad perspective and begins with the following simple definition of Agility: "Agility is the capability to successfully effect, cope with and/or exploit changes in circumstances." Each of the fundamental concepts that are a part of this definition is discussed and a conceptual overview of Agility is provided.

Chapter 4. C2 Agility applies the concept of Agility to the function of C2 which is called management or governance in civilian and governmental organizations. Agility-related measures and ways of creating visualizations of the relative Agility of a C2 Approach or of an Entity capable of adopting multiple approaches are provided. The C2 Agility Conceptual Model (C2ACM) identifies the set of variables that are believed to have a significant impact on Agility. Included in this conceptual model are variables that can be manipulated directly or indirectly to achieve a desired result, as well as other variables whose values are of interest since they shape Entity C2-related performance and effectiveness. These variables, depending upon their values, enable or limit C2 functional performance, the amount of C2 Agility potential an Entity possesses, and the amount that is manifested. Having articulated a C2ACM, SAS-085 turned its attention to seeing if this model was clear, applicable and valid.

Chapter 5. ***Validation*** describes these efforts, which included the design and conduct of a set of experiments as part of an experimentation campaign, the undertaking of a set of case studies, and a consolidated analysis of findings. SAS-085 also held a Peer Review Workshop as part of its validation efforts and has incorporated the feedback received into this final report. The design and conduct of these empirical analyses are provided in two sections.

Chapter 6. Campaign of Experiments and ***Chapter 7. Case Studies*** describe their respective efforts to collect empirical data and summarize their findings with respect to the C2 Agility Conceptual Model (C2ACM) and related hypotheses***.***

Chapter 8. Findings, Conclusions, Way Ahead synthesizes the findings from the experiments and case studies and summarizes the nature of the empirical support for the Agility hypotheses implied by the C2ACM. This section also outlines a way ahead, how NATO and its member Nations could work to operationalize C2 Agility and advance our understanding of C2 Agility.

Chapter 2 – ORIENTATION

This section of the Final Report is intended to provide readers with a synopsis of key developments in the way we have come to think about the nature of mission challenges, an appropriate response to these challenges, and approaches to accomplishing the functions that are associated with C2. Readers who appreciate these developments will see why Agility has become an existential capability and recognize the criticality of adopting an appropriate C2 approach. Since these developments have been the subject of a considerable body of literature, rather that replicate this literature, our objective here is to present just the essential ideas. Interested readers are encouraged to turn to the source materials cited for more in-depth explanations and discussions.

2.1 THE NATURE OF NATO MISSION CHALLENGES

NATO Allied Joint Doctrine is based upon the premise that "the Operational Environment is complex"[8] and states that "All military planning should be coherent with other non-military and potentially multinational and non-governmental initiatives intended to stabilize and create a Self-sustaining secure environment. A NATO military response must therefore be integrated into a wider overall framework for a comprehensive approach."[9] Thus, today's NATO mission challenges rise to the level of Complex Endeavours[10]. They are qualitatively more difficult to understand and meet than the types of missions that have shaped our current organizations, solution strategies, and the ways in which we have traditionally prepared ourselves.

Figure 2-1: Mission Complexity[11] graphically depicts the added complexity that results in moving from a traditional two-dimensional military time and space problem to a multi-dimensional Political, Military, Social, Information, and Infrastructure (PMESII) challenge.[12]

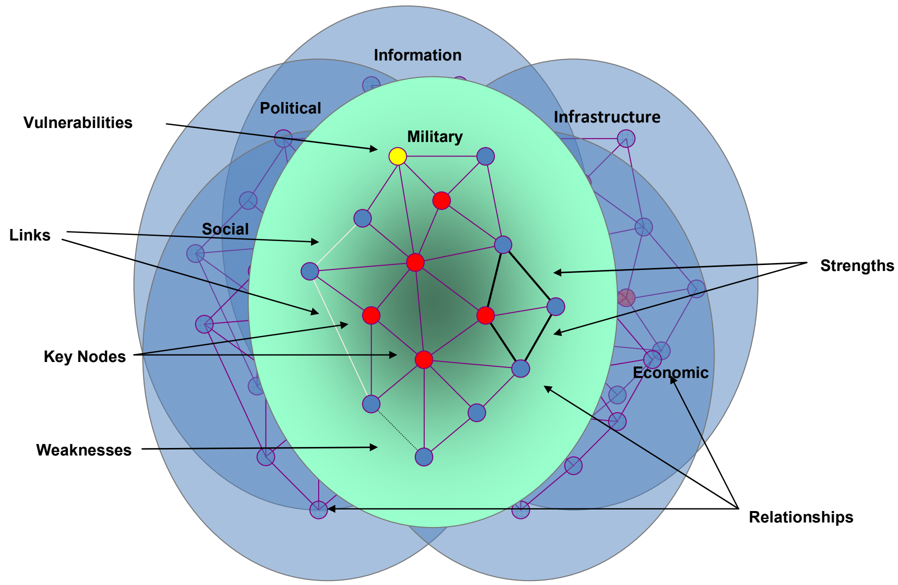
[8] NATO Allied joint doctrine AJP-01(D) December 2010 Preface paragraph 6 section d. page x

[9] Ibid

[10] For the definition and a discussion of Complex Endeavors and their implications for C2 see Alberts, D.S. and Hayes, R.E. Planning: Complex Endeavors, DoD CCRP, Washington, DC 2007 http://www.dodccrp.org/files/Alberts_Planning.pdf

[11] This chart appeared in Mitchell, William, Comprehensive Approach Capacity Building, Implementing the Effects Based Approach to military operations, Royal Danish Defense College ISBN: 9788791421525 Figure 3. Is has been adapted with permission.

[12] PMESII –is a construct for describing actual and desired effects within the environment (i.e. effects space dimensions), while the U.S DIME (*Diplomatic, Information, Military,* and *Economic*) construct, and the similar Canadian 3D plus C (Diplomacy, development, Defence and Commerce) construct describe elements of national power that influence the effects space (Farrell, P. S. E., Allen, D., Burrows, P., Comeau, P., Hugues, S., Kachuik, J…Lichacz, F. (2006). Multi-national Experimentation 4 on Effects Based Approach to operations: CFEC Analysis Report (pp 193) Ottawa, Canada: Defence R&D Canada.)



Source: Visualization of PMESI described in NATO AJP-2(A) WD5 p.51 para.75

Figure 2.1: Mission Complexity

Complex Endeavours involve not only complex problems but are the kinds of problems whose solutions require Complex Enterprises, collections of Entities that possess the diversity of expertise and experience required to both understand the different facets of the problem and their interdependencies, and to assemble the wide range of information and resources necessary to take the actions required. Complex Enterprises differ from traditional organizations with respect to the coherence of the set of objectives of participating individuals and organizations, the degree to which participants share mental models, values, and priorities, the degree to which they develop shared awareness, and their ability to synchronize actions. Thus, while the Entities that are part of a Complex Enterprise collectively could have better access to information and resources, they do not have, as yet, the tried and true organizational constructs and approaches that are needed to bring this information and available resources to bear across the enterprise in a timely manner.

Thus, Complex Endeavours involve challenges associated with both the difficulty of the problem and the difficulty of organizing a response. The solution in both cases is not more of the same, but fundamental changes in both how we 1) approach the solution to these problems and 2) how we best organize to leverage the information and capabilities that are available. The challenges associated with problem or mission complexity and dynamics and those associated with the C2 of a Complex Enterprise are discussed next.

2.2 CHALLENGES OF MISSION COMPLEXITY AND DYNAMICS

Although warfare is inherently complex and dynamic, today's military organizations have evolved to be well-adapted for mission challenges that are *complicated* and relatively stable. [13] [14] Although the distinction between complicated and complex may seem to be only of academic interest, it is a distinction that makes a qualitative difference in the nature of the problem. While complicated problems and the missions undertaken to deal with these problems can be difficult to understand and solve, if one has the appropriate knowledge, experience, information, and resources, even very complicated problems can be understood and, if there is a feasible solution, it can be found by traditional approaches and implemented by traditional organizations and approaches to C2. Furthermore, for complicated problems, it is relatively straight forward to ascertain if solving the problem is worth the effort involved. Sometimes, seeking a partial solution will be the best course of action. Thus, the risks associated with complicated problems can be assessed to determine if the problem is manageable with available resources.

In cases where the problem is solvable and the environment is relatively stable[15], individuals and organizations can, with effort over time, develop a better and better understanding of the problem and improve their ability to solve the problem. In other words, organizations can develop the expertise and experience they need, can reduce the difficulty of these problems by making them familiar ones, acquiring the information sources they need to reduce uncertainty, designing appropriate solution approaches with predictable outcomes that make these problems manageable, and by developing processes that enable them to synchronize needed actions in time and space (physical and effects), they can implement the solutions required in a timely manner. Thus, organizations can learn and adapt themselves to increase their effectiveness and efficiency in dealing with complicated problems.

Relative stability permits individuals and organizations to become increasingly effective and efficient, constrained only by diminishing returns on investment. Organizations that seek to optimize themselves by continuous improvements are held up as exemplars. The net result is that problems that were once extremely difficult to deal with become more and more tractable. Ultimately, solving some complicated problems will become routine. However, one's ability to reduce problem difficulty to manageable levels depends, largely, upon improving the ability to predict both circumstances (a function of understanding the situation) and the effects of various courses of action (need to exercise control).

2.3 COMPLEXITY

"The inherent characteristics of complexity directly challenge our ability to fully understand situations or control outcomes. Complexity makes it difficult, if not impossible, to isolate and understand cause-effect relationships and to predict outcomes. As a result, complexity may also greatly increase risk. 16 Let us review

[13] Readers who wish to explore the differences between complicated and complex problems / missions will find an extended discussion in The Agility Advantage, Chapters 3 and 4 pages 25-60

[14] A discussion of the difference between complicated and complex can be found in Planning: Complex Endeavors pp 11-15.

[15] A situation is relatively stable if the changes that occur are within the ability of the entity to respond in a timely manner. When the pace of change exceeds that which an entity can deal with, the situation is no longer considered to be stable. Thus, stability is not a matter of absolute time frames but relative ones.

[16] Add references

some commonly expressed consequences of complexity and see how it reduces our ability to understand, reduces our control, and increases risk."17 18

2.3.1 The whole is more than…

The whole is more than the sum of the parts. This means that while we may try to decompose complex problems into a series of smaller, simpler problems and solve them independently of one another, the solutions we develop may not work well because there are interdependencies among the problems that have not been accounted for. The ability to decompose problems and tasks is one of the key assumptions that underlie industrial age organizations and management approaches.

2.3.2 Small changes in initial conditions …

Small changes in initial conditions may produce large changes in outcomes. This makes reliable prediction all but impossible in many cases. Even if initial conditions are rather well known, outcomes may be very different from expected.

2.3.3 Small changes …nonlinear …discontinuous

The consequences of small changes in initial conditions may be nonlinear or even discontinuous. This takes away an incremental approach to improvement; that is, an approach that seeks to change a variable until the returns (improvements) diminish and then move on to another variable.

2.3.4 Even perfect in formation …

Even perfect[19] information about the initial conditions is sometimes not sufficient to predict behaviors and outcomes. This aspect of complexity limits the return on investments in information capabilities that can be achieved, and suggests that, while efforts to improve information and analysis capabilities can achieve some reductions in uncertainty, the amount of residual uncertainty present in complex problems will far exceed the residual uncertainty found in the complicated problems of Information Age organizations. Thus, improvement strategies based solely upon improving information are fundamentally flawed.

2.3.5 It is beyond our current abilities …

It is beyond our current abilities to definitively establish cause and effect relationships between and among individual behaviors, collective behaviors, and higher-level outcomes.This means we need to be able to succeed in situations that we do not understand well. This also speaks to a desire for traceability of decisions

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[17] The Agility Advantage – This discussion regarding the impacts of complexity on our ability to understand and control a situation is taken from Chapter 5 Introduction to Agility

[18] One of the few texts on complexity theory that draws heavily on physics for examples that do *not* involve living "agents" is Yaneer Ban-Yam, Dynamics of Complex Systems, Reading Mass.: Perseus Books, 1997. For work undertaken in Australia to inform command and control and with down-to-earth military examples see, e.g., Alex Ryan and Anne-Marie Grisogono, "Hybrid Complex Adaptive Engineered Systems: a Case Study in Defence, New England Complex Systems Institute, *Interjourna*l , 2004 or Ryan's dissertation, "A Multidisciplinary Approach to Complex Systems Design, Univerisity of Adelaide, 2007.

[19] Perfect in this context means that we accurately know the values of the key variables, variables that have a significant impact on (the likelihood of) success.

that are made in the event that these decisions come under scrutiny. Complexity may prevent anyone from establishing causal relationships between outcomes and the decisions that were made.

2.3.6 Global behaviors emerge …

Global behaviors emerge from sets of local interactions that take place. This means we cannot understand or approach problems solely from a top-down perspective that ignores or underestimates interactions.

These six truths, taken together, mean that complex problems are not amendable to approaches that often both assume an ability to predict events with a sufficient degree of assurance and an ability to exercise a sufficient measure of control. Thus, while traditional approaches can be helpful in dealing with aspects of the complex problems we face, we will not be able to solve these problems using traditional approaches alone. The best we can hope for is to be able to anticipate some of the events and can exert some influence and therefore to keep behaviours and effects within acceptable bounds. As a result, we need to be able to augment our traditional problem solving toolkit with ways to effectively deal with the degree of difficulty that is associated with Complex Endeavours. Much of this corresponds to planning for agility (or what others may call Adaptiveness).[20]

In sum, the complexity of the Endeavor Space is, at least in part, a result of the interactions between and among the following dimensions:

- Effects Space (PMESII, entity diversity with respect to competency, culture, values)
- Dynamics (time pressures and lack of stability)

2.4 AGILITY: A NECESSARY RESPONSE

Today's military organizations are highly professional and possess capabilities found in no other types of organization. They perform superbly when dealing with the traditional military missions, for which they are well-prepared and equipped. However, when faced with non-traditional missions where problems are unanticipated and where actions have unintended consequences, they have had to rely upon innovating "on the fly" to overcome the adverse impacts of approaches, processes, systems and materiel that were ill-suited for the tasks at hand. There are two "lessons" would be a mistake to take away from these experiences. The first of these is that more needs to be invested in: 1) an ability to better predict and prepare for these problems, and 2) developing a better understanding of the consequences of courses of action. However, when faced with a Complex Endeavour, such approaches have inherent limits and may, at times, be counter-productive. As discussed above, just seeking more information is unlikely if the uncertainty in question stems from complexity. This may explain why, after decades of investments in information systems, some feel there

20 Many of the same issues have been treated in discussions of planning under uncertainty and capabilities-base planning. See Paul K. Davis, "Lessons for C2 Investment from Capabilities-Based Planning," Proceedings of the 18th ICCRTS, Paper I-007, June 19-June 21, 2013 and references therein, the most recent of which is a review, Paul K. Davis, Lessons from RAND's Work on Planning Under Uncertainty for National Security, Santa Monica, Calif.: RAND, 2012. The review cites examples form domains as different as logistics, acquisition and force planning; it also points to social policy-analysis literature in the United States and Europe.

has been relatively little return on investment[21]. Clearly, we have increased our access to information and improved its quality. Yet despite these improvements, the problems seem as difficult as ever. Perhaps this is because we are taking on more difficult problems and we are beginning to recognize and acknowledge the difficulties that were always present since now NATO and its member nations have experienced these difficulties.

Many seem to think that we have only managed to add to our problems by creating information overload. There is, of course, a limitless list of improvements we could make to our information-related capabilities. Some believe this would make things better. Indeed, they might. Some have misinterpreted Network Centric Warfare[22], Network Enabled Capability, and Network Enabled Operations[23] and have focused mainly on the technology and the information domain (e.g. getting the right information to the right people at the right time) rather than focusing on the cognitive and social domains (the development of shared awareness, the interactions between and among entities, and Self-synchronization) However, it has become increasingly clear that perhaps we need to rethink how we view the problem and our problem solving approach.

It is time to step back and consider what it will take to be successful in Complex Endeavours. First, we will need to find ways to cope with somewhat *unfamiliar* situations, ones that we do not completely understand. When we do not fully understand a situation, we cannot be certain what the appropriate response should be. Thus, we need to be prepared when and if the response we have selected is not successful or if it is initially successful, we need to be prepared in case it is no longer working well enough. This implies that we are capable of ascertaining whether or not the selected response is working well enough and if not be able to choose and implement a different course of action. Even if our response initially seems to be working, we need to keep in mind that we face adaptive adversaries that have shown a capability to make adjustments and, at least to some extent, make our actions less effective.

Having more than one option or way of accomplishing something is what we call, flexibility. Being able to recognize that something is not working and take corrective action in a timely manner is what we call, responsiveness. Flexibility and responsiveness are two of a set of basic capabilities that are associated with Agility. Thinking about developing Requisite Agility[24] rather than trying to optimize our effectiveness in dealing

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[21] The following discussion about the ROI of IT investments is taken from Vogel, Lynn, IT Investments: Exploring the Elusive ROI in Healthcare Journal of Healthcare Information Management — Vol. 17, No. 4 - Economists observed that the growth in U.S. labor productivity averaged almost 3 percent per year over the entire period from the end of World War II until the early 1970s. At that point, however, productivity across the U.S. economy began to stagnate, averaging about 1.4 percent per year. During the period 1974-1995, economists determined that productivity growth was only increasing at an average rate of 1.4 percent per year, rebounding somewhat to an average rate of 2.5 percent between 1996 and 2000. See McKinsey Global Institute. US Productivity Growth 1995-2000, Understanding the Contribution of Information Technology Relative to Other Factors, October 2001. Available at http://www.mckinsey.com/knowledge/mgi/feature . In the same general time frame, as noted in recent research by McKinsey and Company, “the rate of nominal business investment in information technology surged to 17 percent per year, from its 1987-1995 rate of 9 percent.” From this data, it was assumed that even with new and increasing investments in information technology, for some unexplained reason productivity was not only not keeping pace, but had actually decreased from previous levels.

[22] Alberts, D. S., Garstka, J., and Stein, F.(1999), “Network Centric Warfare, DoDCCRP, Washington D.C.

[23] Sharpe, J and English, A. (2006) Network Enabled Operations: The Experiences of senior Canadian Commanders. In Stewart, K. (Ed.) (pp 64) Toronto: Defence R&D Canada.

[24] Agility is not free, nor is it always desirable. Therefore it makes sense to possess the amount of Agility required by the situation (called Requisite Agility) - adapted from NATO NEC C2 Maturity Model p.279

with current challenges opens up a new avenue along which we can improve. In his book on Cybernetics, Ashby introduced the concept of Requisite Variety[25] which stated that “The larger the variety of actions available to a control system, the larger the variety of perturbations it is able to compensate.” While it is unrealistic to think that one can exercise “control” over a Complex Endeavor, Agility enables one to increase the variety of the ways and means that can be brought to bear to influence outcomes.

To explore this idea, we will first focus on the nature of agility in general and then shift our attention to C2 Agility

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> “Agility is not a way of reducing problem difficulty, but rather a way of dealing with the combined effects of the presence of complexity and uncertainty. Even if complexity were not present, certain situations or problems have significant levels of uncertainty that require Agility.” The Agility Advantage p.61

Taking a decision to increase Agility does not mean that one should abandon efforts to better understand a situation and/or reduce uncertainty. However, we must appreciate “deep uncertainty” and learn to expect the unexpected. Current approaches and investments are decidedly out of balance with far too much effort and too many resources being spent to reduce uncertainty rather than to cope effectively with residual uncertainties, which are sometimes large and cannot be eliminated. In other literatures, the problem of deep uncertainty is characterized as “black swans.”[26]

2.5 CHALLENGE OF C2 FOR COMPLEX ENTERPRISES

Traditional military missions can be accomplished by one or more military organizations and thus, traditional approaches to C2 are well suited for these endeavours. Complex Enterprises differ in important ways from traditional military organizations or a multi-national military force. Understanding the differences is critical. While traditional military C2 “requires” a single hierarchy (integrated chain of command), Complex Enterprises, as described in Alberts and Hayes (2007)[27] , consist of a large number of diverse participants such that multiple interdependent “chains of command” exist; the objective functions of the participants conflict with one another or their components have significantly different weights; and/or, the participants’ perceptions of the situation differ in important ways. Thus, the functions associated with C2 (decision making, information acquisition, analysis, sharing and exploitation) need to be accomplished differently.

SAS-065 uses the term ‘entity’ to refer to the focus of the analysis. Since agility is a concept that applies to individuals, teams, organizations, systems, processes, and approaches, an entity can refer to any of these. Thus, organizational agility and approach agility, for example, are included concepts. Given that Complex Enterprises involve multiple chains of command[28], how we approach accomplishing the functions associated

[25] Ashby, W. Ross (1956): An Introduction to Cybernetics, (Chapman & Hall, London)

[26] See Nassim Nicholoas Taleb (2007). The Black Swan: the Impact of the highly Improbable, Allen Lane Publishers.

[27] Alberts and Hayes: Planning Complex Endeavors, DoD CCRP Publication Series, Washington, DC 2007

[28] Complex Endeavors may include, but are not limited to, municipal, regional, national, and international military, police, diplomatic, and development organizations.

with C2 needs to be viewed from two perspectives: first, from the familiar perspective of an individual Entity; and second, from the perspective of a Collective (an assemblage of a large number of independent, yet interdependent Entities). Thus, it is critical that we develop a better understanding of the appropriateness of different Entity and Collective approaches to C2 and the ways in which each affects the overall effectiveness of both individual Entities and of the Collective. Much of the doctrinal and scholarly writing about C2 has, until quite recently, focused almost exclusively on a single Entity. Much more work is needed on C2 for Collectives, collections of independent, yet interdependent Entities that have not entered into a "union" that creates an integrated Entity.

In 2007, a special issue of the International C2 Journal was devoted to the future of C2. The lead paper[29] took aim at the traditional view and definition of C2 and stressed the importance of being able to accomplish the functions associated with C2 for ad hoc Collectives comprised of a large number of independent, yet interdependent Entities with common immediate interests but not identical objectives. In other words, this paper stressed the importance of coming to grips with "C2 for Complex Enterprises."

Analogous to the increase in complexity and dynamics that are associated with a movement from a purely military problem to a DIME or PMESII one, there is a similar increase in complexity and dynamics when moving from integrated military organizations to a Complex Enterprise and recognizing heterogeneity within an entity or collective. As such, not only do we need to "re-invent" C2 so that it is applicable for a heterogeneous Collective but do so in a way that each of the various approaches to C2 are, in of themselves, more agile. The traditional view of C2 is synonymous with a traditional military organization and its hierarchical, stove-piped processes. In other words, there is a basic one size fits all approach which can be tailored at the margins to suit a particular commander's style. C2 for a Complex Enterprise is not a single approach[30]. As will be illustrated in the case studies later in this report, different participating Entities and subsets of Entities, for a variety of factors will at least initially employ different approaches to C2. As an endeavour proceeds, individual and Collective C2 will evolve and may (or may not) become increasingly homogeneous.

The challenge for individual Entities and the Collective as a whole is to develop the capability to appropriately employ multiple approaches and 'coordinate' their adoption in ways that make sense. In other words, the challenge is to tailor one's approach to C2 to fit the enterprise, mission and circumstances.

2.6 EVOLUTION OF C2

For the reasons mentioned above, then, our thinking about C2 is changing as we better appreciate the special features of complex endeavours (including some historical wars, such as WW II or NATO's interventions in the Balkans). Previously, thinking about C2 had changed little for the better part of two centuries, and in some ways, for two millennia. The first use of the term, as noted in the NATO NEC C2 Maturity Model, dates to the 19th century. [31] "The term *command and control* is clearly a product of the Industrial Age. The first use of the

[29] Alberts, D. S., Agility, Focus and Convergence: The Future of Command and Control, International C2 Journal, Volume 1, No 1, Spring 2007

[30] See Annex A

[31] NATO NEC C2 Maturity Model, SAS-065, DoD CCRP Publication Series, Washington, DC - See pages 13-23

term as we understand it appears to be by Jomini[32] in *The Art of War*. It emerges as a term of art around the middle of the last century when President Truman instructs General MacArthur to "take command and control of the forces."[33] Prior to this *command* was always associated with a commander (an individual) with the development of a staff with Gustavus Adolphus (1594-1632) and its subsequent refinement with Napoleon Bonaparte, a headquarters or management team. This anthropomorphized view of command persists to this day as many military organizations define C2 as a commander's exercise of authority. This, of course, does not speak at all to how the function of C2 is or could be exercised and what may be appropriate or inappropriate for a given organization that has taken on a particular mission under a certain set of circumstances.

By the late 18th century, central control of forces was becoming unrealistic as the range and accuracy of weapons improved forcing dispersion[34]. As forces became increasingly geographically dispersed, the force that could effectively delegate command authority (decision rights in the parlance of SAS-050's C2 Approach Space) had the advantage. For delegation to be effective, however, shared understanding was needed. Prior to the information Age, shared understanding was achieved through doctrine and training and required high caliber, experienced, professional soldiers.

Allocating decision rights not only requires a level of familiarity and trust between commanders and subordinates but also must go hand-in-hand with developing a shared understanding of the situation including command intent. Napoleon's approach to C2 involved sharing his vision with Corps commanders and giving them latitude. At the turn of the 19th Century a parallel development took place in Prussia where centralized command and reliance on the ability of the commander (what some call "commander centric" today) was replaced by "Directive command" and "Fuhren durch Auftrag" (leading by task). Although the words "directing" and "tasking" may be interpreted as a form of micro-management, this development was actually a move towards an approach to command that provides commander's intent and gives subordinates a great deal of freedom of action. This development that was vigorously resisted by some commanders who preferred to continue to lead by orders (Fuhren durch Befehl). While the debate about the appropriate way to delegate decision rights continues until this time, we have moved from the Industrial Age to the Information Age and have capabilities that were not available previously. These capabilities could be used to improve shared awareness and make commander more comfortable with more delegation of decision rights.

With the advent of the Information Age and the arrival of its transforming capabilities, new ways of accomplishing the function(s) of C2 became available. Some of these opportunities result from capabilities that never before existed, while others are a result of the changes to the economics of information that made existing capabilities more affordable. Since existing C2 Approaches are based upon a set of assumptions regarding what was possible and the economics (costs and benefits) associated with different approaches at some point in time, at least some of these assumptions may no longer hold. Thus, the Information Age, having made some of these assumptions obsolete, offers militaries the opportunity to rethink their existing approaches to C2.

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[32] Baron Antione Henri de Jomini, *The Art of War*. New York, NY: Greenhill Press, 1838. Chapter 2, Article 14. "The Command of Armies and the Supreme Control of operations." *Precis de l'Art de Guerre*. 1996.

[33] MacArthur, Douglas, Reminiscences, McGraw-Hill, New York, 1964.

[34] The points in this paragraph are drawn from Stewart, Keith, The Evolution of Command Approach, 15th ICCRTS http://www.dodccrp.org/events/15th_iccrts_2010/presentations/192.pdf

2.7 C2 APPROACH SPACE

Although individual militaries have approached C2 differently, at different times for different challenges, it was only recently that an overall framework was developed that identified the space of C2 Approach options by considering differences along three fundamental dimensions. If one wants to think about how the functions of C2 could be accomplished and select, from among the set of possibilities, an appropriate approach, it is necessary to be able to 1) describe and understand what makes one approach different from another approach, and 2) define a set of possible approaches.

The C2 Approach Space was introduced in 2004 during a series of technical meetings of the DoD CCRP's Information Age Metrics Working Group (IAMWG) and adopted by SAS-050[35], providing a conceptual framework for thinking about what approaches are possible and how they differ from one another. An Entity's C2 Approach can be defined as a specific region[36] within a three-dimensional C2 Approach Space. A region defined by specific ranges for each of the following three dimensions of this space (see Figure 2.2: C2 Approach Space).

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

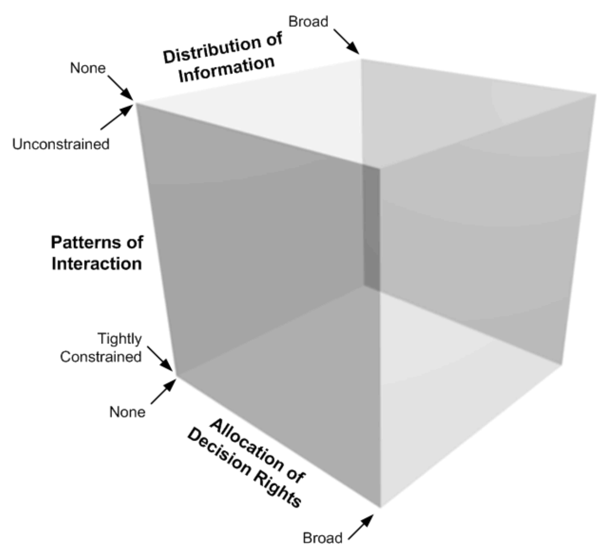

Figure 2-2: C2 Approach Space

These three dimensions, while logically independent should be inter-dependent in practice. When an entity's organizational structure, process, and information sharing policy constrains patterns of interaction and information flows without consideration of the allocation of decision rights, dysfunctional behaviors can occur.

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[35] SAS-050 http://ftp.rta.nato.int/public//PubFullText/RTO/TR/RTO-TR-SAS-050///TR-SAS-050-02.pdf

[36] A C2 Approach is represented by a region rather than a point in C2 Approach Space because there are differences in the ways that a particular approach to C2 can be implemented.

Hence, it makes more sense to treat these dimensions as being inter-dependent in practice. For example, how decision rights are allocated should shape the patterns of interactions that emerge, and together these two variables should determine the distribution of information.

There are a number of factors that will ultimately affect where in the C2 Approach Space an entity chooses to operate as well as where an entity is capable of operating. In Collectives, the degree to which the set of entities share intent may be the most significant factor in determining what, if any decision rights are allocated to the Collective. Trust between and among that participating entities will play a role in determining who interacts with whom and what information is shared. Systems capabilities as well as circumstances determine what is possible.

2.8 NETWORK ENABLED C2

Improvements in communications and information technologies, if properly leveraged, can facilitate shared awareness and shared understanding across dispersed forces. A robustly networked force makes it feasible for commanders to 'move to the edge' as depicted in Figure 2.3 Network Enabled C2. 'Moving to the edge' involves approaches to C2 that are characterized by increased information sharing and collaboration.

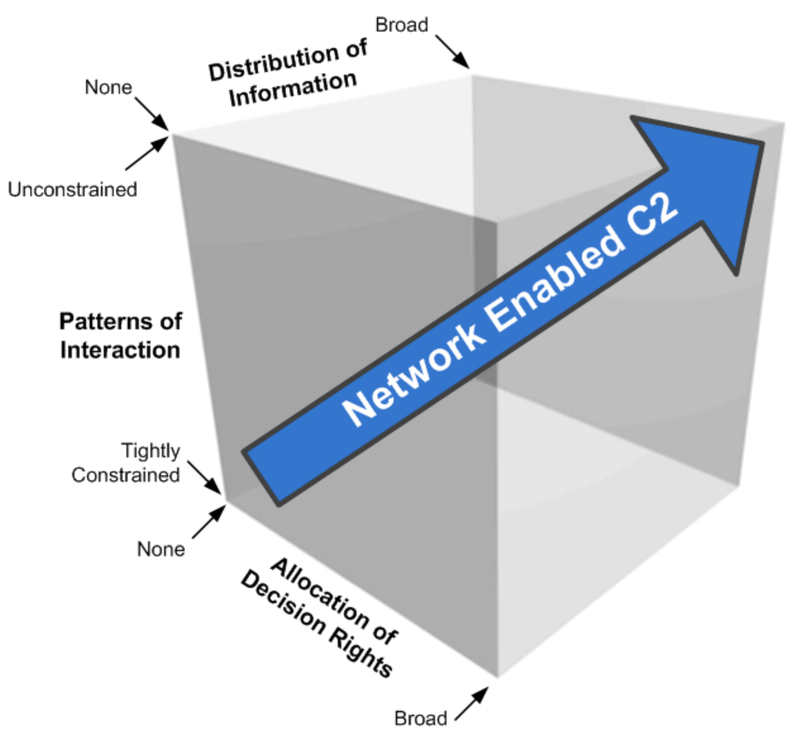


Figure 2.3: Network Enabled C2

In theory, this not only improves the quality of awareness but makes it possible to achieve high levels of shared awareness. High levels of shared awareness create opportunities for Self-synchronization that can greatly increase the effectiveness of the force.[37] However, it does not follow that entities should shun traditional or less networked-enabled approaches to C2 in favor of adopting the most networked-enabled approach possible. The advantages and disadvantages of moving toward or to the edge as well as the relationship between being network enabled C2 and C2 Agility are explored in the remainder of this report.

At the Prague Summit in November 2002, NATO recognized that transformation of the military based upon Information Age principles was essential, and pursued a course of transformation denoted as NATO Network-Enabled Capabilities (NNEC).

In November 2003, nine NATO nations (Canada, France, Germany, Italy, The Netherlands, Norway, Spain, The United Kingdom and The United States) signed an arrangement to join in funding a feasibility study on NATO Network Enabled Capability (NNEC) as an important step towards NATO transformation. NEC has been adopted by NATO and many of its member nations and has and continues to shape the way these forces organize, equip and operate. Given the enormity of the task (NEC transformation), a transition period, as depicted in Figure 2.4: NATO Transition to NEC was envisioned; one where capability would become available in increments and with these capabilities more network-centric approaches to C2 would be adopted.

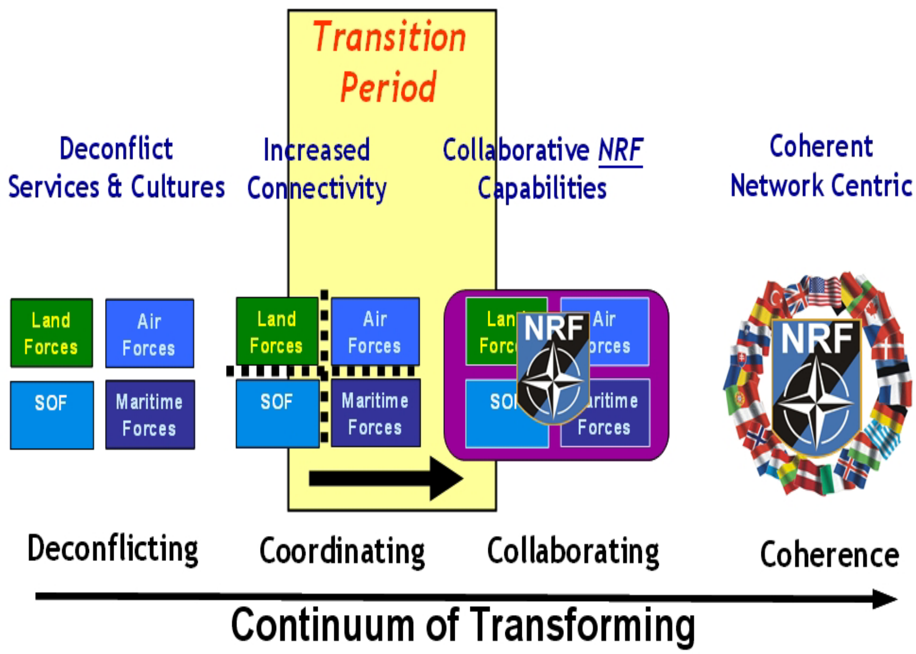


Figure 2.4: NATO Transition to NEC

[37] This proposition was expressed in the form of the tenets of Network Centric Warfare. See the NCW Report to Congress – Executive Summary http://www.dodccrp.org/files/ncw_report/report/ncw_exec_sum.pdf

2.9 NATO NEC C2 MATURITY MODEL

SAS-065 was chartered in 2006 to develop a NATO NEC C2 Maturity Model (N2C2M2), that defined the characteristics and capabilities of the approach to C2 needed to support each of the four NATO NEC capability levels that ranged from de-conflicting to coherence[38] (see Figure 2II.5: NATO NEC C2 Maturity Model Approaches). The basic building blocks of the maturity model are approaches to C2[39] that were designed to possess the capability necessary to support each of the NATO NEC Capability levels.

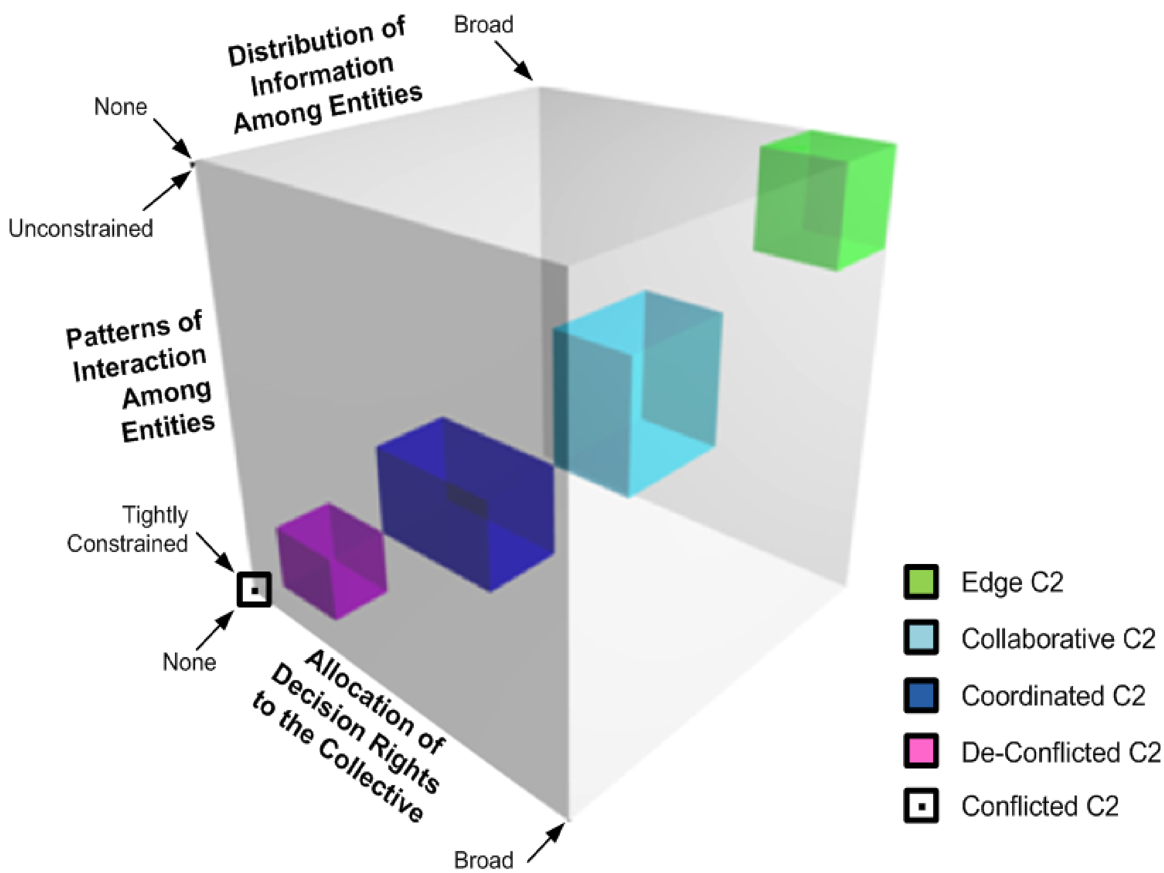


Figure 2.5: NATO NEC C2 Maturity Model Approaches

[38] NATO NEC Feasibility Study http://www.dodccrp.org/files/nnec_fs_executive_summary_2.0_nu.pdf

[39] The "fifth" approach to C2, Conflicted C2, while also depicted in this figure is not considered to be a Collective C2 Approach although it is clearly an option. In Conflicted C2, the entities do not allocate any decision rights to the Collective, nor do they interact with other entities, nor do they shared information with others. Thus, there is no "Collective C2", only Entity C2 because the entities operate entirely independently and thus have a significant likelihood of getting in each other's way.

The N2C2M2 describes each of these five C2 Approach archetypes (Conflicted, De-conflicted, Coordinated, Collaborative, and Edge) and locates them in different regions of the C2 Approach Space. The approach space depicted in Figure 2.5 differs from the space depicted in Figure 2.2 in that the axis have be re-labelled to reflect the need to move from the perspective of an individual organization to that of a Coalition or Collective. Thus, the ADR axis does not apply to the way decision rights are allocated within an entity; rather it refers to the allocation of decision rights from individual entities to a collective. In a similar vein, the interactions axis is about interactions between and among the various Entities that constitute a complex enterprise. The distribution of information axis focuses, likewise, on inter-organizational sharing rather than intra-organizational sharing.

SAS-065 made the assumption that Entities could always revert to less network centric approaches if and when appropriate. Thus, Entities could locate themselves in the C2 Approach Space in response to the mission and circumstances and maneuver in the C2 Approach Space to a more appropriate location as circumstances changed. Thus, SAS-065 defined C2 Maturity levels are depicted in Figure 2.6: Maturity Levels and the C2 Approach Space.

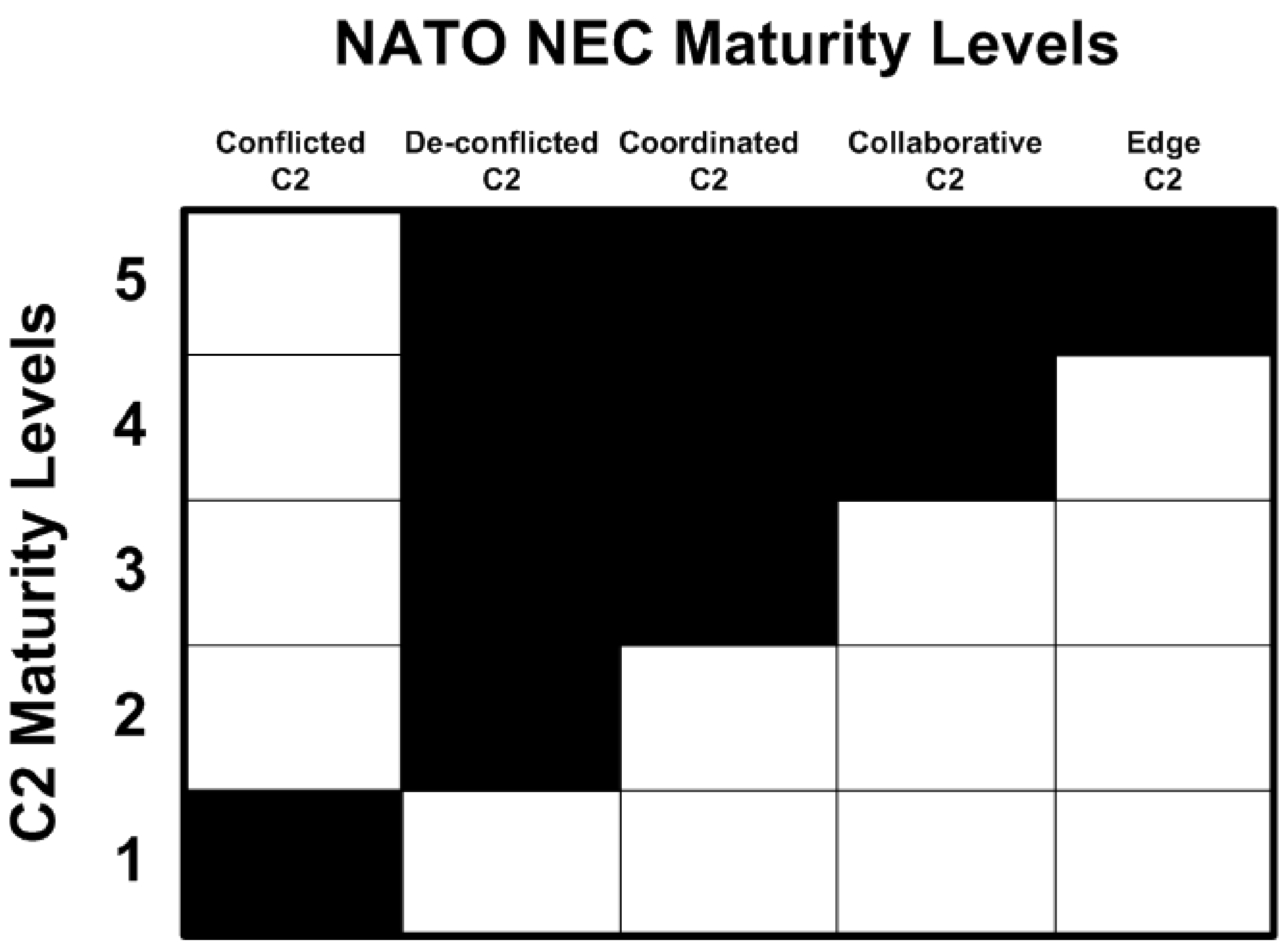
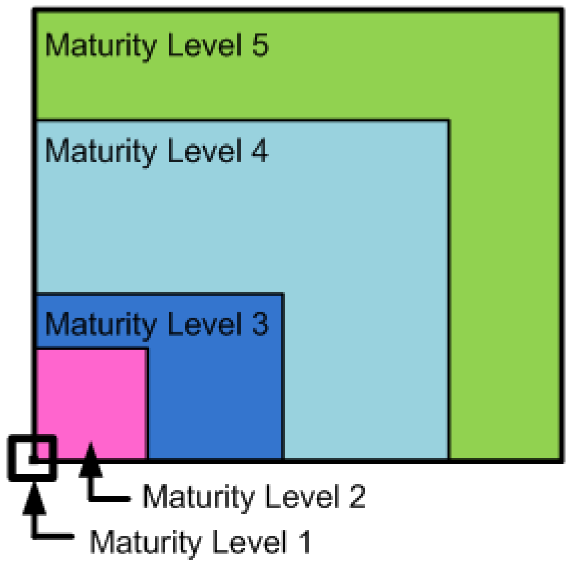


Figure 2.6: NEC C2 Maturity Levels and C2 Approach Toolkit.

Since each successive maturity level includes all of the C2 options of lower levels of maturity, higher maturity levels cover increasingly larger regions of the C2 Approach Space and, at Level 5, an Entity can operate in any part of the space as depicted in Figure 2.7: Maturity Levels and the C2 Approach Space Coverage.



. **Figure 2.7: Maturity Levels and the C2 Approach Space Coverage**

The N2C2M2 provides ordinal scales[40] for each of these C2 Approach Space dimensions. Distribution of Information (DoI), for example, ranges from "none" to "broad". Verbal descriptions of what is required to move from one C2 Approach to another are also provided by the N2C2M2[41]. These can be used to determine the approach region that is appropriate for a particular C2 Approach, that is, to classify an approach as one of the five C2 Approaches identified in Figure 2.5. Moving along the DoI dimension to get from Conflicted (none) to De-Conflicted requires sharing of information pertaining to seams and constraints. To move from De-Conflicted to Coordinated more information dissemination is required to coordinate selected plans and/or activities. On the other end of the DoI scale is "broad" which is described as moving from a need to know to a need to share.

These verbal descriptions while useful to make distinctions between and among qualitatively different C2 Approaches do not provide the granularity needed for more detailed analysis. SAS-085 developed quantitative scales for each of these dimensions but did not define breakpoints that indicated where the boundaries between the different C2 approaches should be. Rather, SAS-085 wanted to see if the observed locations in the C2 Approach Space (determined quantitatively in the experiments and qualitatively in the case studies) did

[40] A variable with an ordinal scale is one in which the order matters, that is moving along the scale in one direction represents more of, in this case, delegation of decision rights, richer patterns of interaction, and wider distribution of information. However, the intervals between the points on the scale are not known to be equal.

[41] See N2C2M2 C2 Approach Transition Requirements, pp. 67-69

indeed create loci of points that corresponded to unambiguous regions. That is, did different C2 Approaches actually occupy different regions of the C2 Approach Space?

2.10 ON V. OFF DIAGONAL C2 APPROACHES

SAS-065 placed the five C2 Approaches along a diagonal of the C2 Approach Space because it was felt that movement along any one dimension needed to be accompanied by movement along the other two dimensions to achieve an appropriate balance among decision rights, interactions, and information dissemination

Approaches along this diagonal were thought to be "co-evolved." Co-evolution is a basic tenet of networked enabled capability reflecting the need to make appropriate changes in doctrine, organization, training, material, leadership, personnel, facilities and information (DOTMLP-FI) to take advantage of, say, advances in information-related capabilities. Given that the C2 Approach Space employed by SAS-065 and others did not specify quantitative scales for the three approach axes, the depiction of a diagonal was taken to be symbolic of appropriately co-evolved approaches. Thus, when ADR becomes more widely-distributed (as is the case as the C2 approaches become more network-enabled) that movement also occurs along the PoI and DoI axes. The "white space" in these depictions of the C2 Approach Space seems to imply that no useful C2 approaches can be found off this diagonal.

SAS-085, while recognizing the need for appropriate co-evolution, reasoned somewhat differently. We conclude that "off-diagonal" approaches to C2 have merit under certain circumstances. Also, as a separate consideration, entities may not be able to move, in the near term, along the diagonal, but may be able to move along one or two of these three dimensions. Thus, SAS-085 concluded that "off-diagonal" approaches as well as those that are on the diagonal need to be understood. Therefore, SAS-085 looked for and examined both on and off diagonal approaches in experiments and case studies. This proved especially appropriate when considering real-world heterogeneity of Collectives. As mentioned in Anex A, such a Collective will need a set of C2 Approaches to facilitate the interactions and information flows needed between and among various participating entities. In aggregate, this corresponds to being "off-diagonal." Related observations were noted by peer reviewers who were sensitive to heterogeneity issues related to degrees of trust, alignment of objectives, and technical and professional maturity. Although SAS-065 depicted Collective C2 Approaches as being homogeneous, they noted the existence of C2 heterogeneity in their case studies.

2.11 C2 APPROACH MATURITY VS. C2 MATURITY

SAS-065 made a distinction between the "maturity of a specific C2 Approach" and an Entity's C2 Maturity, the latter being one of the five levels defined in the N2C2M2. The use of the word "maturity" in association with a particular approach to C2 dates back to the original articulation of Network Centric Warfare (or NEC as terminology has evolved). The C2 Maturity levels were defined to explain how organizations might be expected to evolve in a series of steps or stages from their current capabilities and approaches to full-up network-centric capabilities. This maturity model was developed with the goal of providing a path that organizations could employ to mature their C2 capabilities and approaches over time. The Network Centric Maturity Model,[42] depicted in Figure 2.8 presents five levels of network centric maturity, where more network-

[42] The Network Centric Maturity model was introduced in Alberts, et al, "Understanding Information Age Warfare", DoD CCRP Publication Series, Washington, D.C., 2001. p.241. http://www.dodccrp.org/files/Alberts_UIAW.pdf

centric entities are able to develop greater levels of shared awareness that, in turn, enables them to self-synchronize[43].

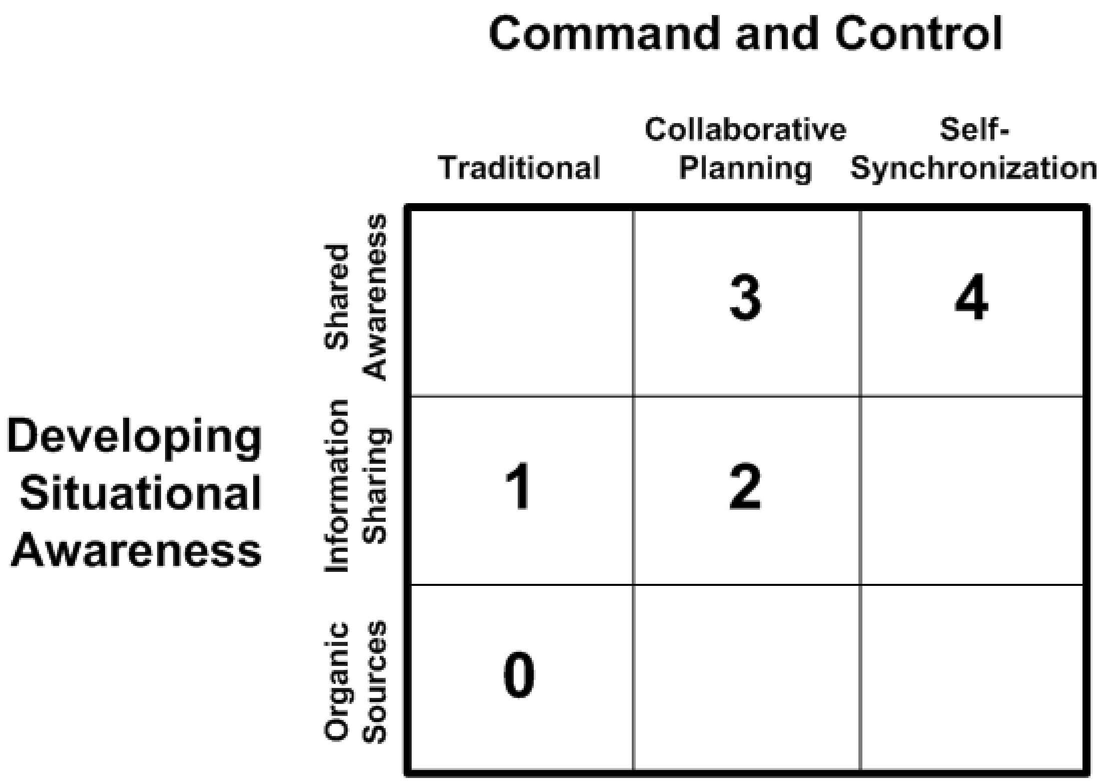


Figure 2.8: Network Centric Maturity Model

The network centric maturity model was originally developed to serve as a benchmark to measure progress toward NCW (NEC) or NEC. Thus, the word maturity, as it was used at this point in time, measured one's degree of net-centricity – a reflection of the maturity of the organization's efforts to develop NEC. Entities that are able to operate in the "Edge" corner of the C2 Approach Space were considered "mature". Readers are reminded that while the ability to operate at or near the "Edge" corner of the C2 Approach Space often is desirable because, for some sets of missions and circumstances, it is the most appropriate C2 Approach option. This does not mean that an entity should always operate in this region of the C2 Approach Space. The N2C2M2 concept of C2 Maturity reinforces this by requiring entities to maneuver in larger regions of the C2 Approach Space as they become more mature.

[43] Later in this report, evidence will be provided that establish a link between network centric maturity and agility. The ability to self-synchronize increases agility.

2.12 HETEROGENEOUS C2

Mandated by NATO-RTO-SAS, the initial concept of the N2C2M2 was designed by SAS-065 to assist NATO partners in the development of roadmaps for improving their C2 systems thus eventually reaching a *homogeneous* collective NATO C2 system for effective (joint and combined) "Coherent Network Centric" military operations (see Figure 2.4: NATO Transition to NEC). That was arguably perceived to suggest Edge C2 as a "one size fits all" idealization.

The initial concept evolved substantially during the SAS-065 and SAS-085 studies as it was recognized, and as real world evidence confirmed that 1) operations involving NATO often included creating collectives involving non-NATO partners and 2) a homogeneous C2 approach was neither feasible, nor was it a useful ideal for non-military aspects of operations such as those in stabilization and reconstruction, or even for military aspects when involving non-NATO partners. Non-homogeneity has been strikingly evident in disaster-response operations in which military forces largely played critical, albeit supporting roles. Finally, from SAS-065 case studies and the results of experiments (reinforced by those conducted by SAS-085) it has become increasingly clear that Edge C2 is not always the best approach. Thus, C2 Maturity should be seen as enabling transitions among the various C2 Approaches (conflicted, de-conflicted, cooperative, and edge) so that the best or at least, an appropriate C2 Approach can be adopted.[44]

As a result, SAS-065 came to view the cube model of C2 approach (Fig. 2.5) in terms of how a set of disparate, yet more or less interdependent, entities – that is a collective of entities undertaking a complex endeavor (Alberts and Hayes, 2007) – can achieve focus and convergence by moving entities up or down on the diagonal (from Conflicted at the lower left hand corner to Edge at the upper right hand corner of the cube) to converge on whatever C2 approach is appropriate in the situation at hand given the C2 maturity / C2 agility of the participants' C2 systems. The case studies demonstrated that heterogeneity of C2 approaches is the norm in complex endeavors and convergence would not necessarily occur over time.

A Collective's C2 Approach in a complex endeavor will – almost by definition – be heterogeneous at the outset. Whether the C2 approach should evolve to become more homogeneous will depend on circumstances such as the nature and dynamics of the endeavor, the C2 agility of the partners or entities, whether sufficient time is available for evolution, and whether or not the partners share common objectives and trust each other.[45]

[44] The insights SAS-065 obtained from its case studies and experiments were reinforced by the validation studies performed by SAS-085.

[45] Huber and Moffat (2010) have proposed using the N2C2M2 as a conceptual framework for the evolution of convergent defense planning in Europe, as called for by Force transformation in NATO and more recently by the more modest concept of "Smart Defense." Interestingly, this evolution will itself be a highly complex endeavor involving all European governments and numerous military and industrial stakeholders in Europe and the United States with diverging interests and objectives. In contrast to complex endeavors in the areas of combat operations, peacekeeping and stabilization as well as response to large-scale man-made and natural disasters, time is a controllable factor, at least in principle. This is confirmed by the SAS-085 validation case study on the development and testing of an agile C2 system for the security of the Vancouver Olympics (Farrell, 2010).

Because of limitations in trust and differences in capabilities, interactions and information sharing among entities as well as the allocation of decision rights may be deliberately limited.

Unfortunately, Collective C2 Maturity and C2 Agility are not easily measured when C2 is heterogeneous. In fact, an assessment of collective C2 boils down to the difficult problem of maximizing effectiveness of the endeavor given the different C2 approaches and operational capabilities of the participating entities for performing the tasks essential for success of the endeavor, and given the constraints to be considered when negotiating a heterogeneous C2 approach for the collective.

Thus, for assessing the C 2 maturity and agility of heterogeneous C2, the conceptual C2 models needs to consider context-dependent considerations that permit, e.g., building task clusters that match capabilities to needs and account for sharing of objectives and degrees of trust. To this end, it is necessary to specify the endeavors in considerable degree, which necessitates use of scenarios in planning. For a more detailed discussion of such matters the reader is referred to Davis and Huber (2012) at Annex III of this report.

2.13 SAS-065 CASE STUDY FINDINGS

SAS-065 conducted a set of retrospective case studies to see whether or not the C2 Maturity Model was useful in helping to understand why some Complex Endeavours were more successful than others; and if so, to see whether conclusions could be inferred as to when particular C2 Approaches were appropriate.

Indeed, SAS-065 found that the effectiveness of a Complex Endeavour depended upon the appropriateness of the Collective's C2 Approach; that more network-enabled C2 Approaches were needed for the most challenging (dynamic and complex) missions. SAS-065 observed that more network-enabled C2 Approaches were sometimes adopted or evolved in the cases studied. The lack of success observed in particular endeavours was attributed to an inability of the Collective to adopt an appropriate approach (in all cases a more network-enabled approach) to Collective C2. In other words, these failures involved 1) not properly 'locating' themselves initially in the C2 Approach Space and/or 2) a lack of maneuver ability in this space when the C2 Approach adopted was not appropriate.

The inability to adopt an appropriate approach in turn was traced to a lack of: trust, interoperability, information sharing, collaboration mechanisms, and also to culture differences. These differences were most notable between military and non-military organizations that limited the C2 Approach options available. A failure to adopt an appropriate approach was hypothesized to involve one of the following: 1) a failure to recognize that the current approach was inappropriate for the situation in the first place, 2) a significant change in the situation that rendered the current approach no longer appropriate, and 3) no other approach options were available, even though it was recognized that there were problems with the current approach.

This led SAS-065 to the conclusion that the requirement for achieving success in Complex Endeavors includes 1) having more than one approach option in an Entity's toolkit, 2) being able to understand the conditions and circumstances that determine the appropriateness or inappropriateness of each option, and 3) having the ability to transition to an appropriate approach. Together these are identified as key conceptual components of the C2 Agility Conceptual Model, later in this report.

While SAS-065 adequately demonstrated that C2 Maturity and C2 Agility are related, more research and practical applications were needed to understand these two concepts and NATO needed a richer understanding of how C2 Agility contributes to overall force Agility, which requires the co-evolution of all the Lines of Development dimensions (e.g. DOTMLP-FI).

2.14 NATO RESEARCH GROUP SAS-085

SAS-085 took over where SAS-065 left off. Previous research and experience indicated that the logical response to high degrees of uncertainty and complexity is to improve Agility. Agility, like any other "good", is not an end unto itself and thus simply seeking maximum Agility is not the answer. In theory, there is an appropriate amount of Agility given an Entity's "Endeavour Space" (the set of future missions and the circumstances). SAS-065 called this appropriate amount of Agility, "Requisite Agility." Therefore, SAS-085 sought to improve our understanding of C2 Agility, its prerequisites (causes) and effects, and the degree to which Agility is needed. Previous NATO research groups treated Agility as an unspecified combination of six attributes—robustness, responsiveness, resilience, flexibility, innovation, and adaptation of structures and processes. In order to make further progress and move Agility from a concept to an operational capability, SAS-085 sought to develop a better understanding of these attributes, their composition, and their relationships with one another and overall C2 capability.

2.15 RECENT DEVELOPMENTS AND NATIONAL PERSPECTIVES

SAS-085 has noted some recent developments related to either the need for increased C2 Agility or the efforts of member Nations to understand and improve their C2 Agility. This section highlights some of these.

2.15.1 Canada

The Integrated Capstone Concept document (ICC)[46] concluded that the demands of the future security environment will require the Canadian Forces to adopt comprehensive, integrated, adaptive, and networked approaches in order to remain strategically relevant, operationally responsive, and tactically decisive in the execution of national intent (CFD, 2009). The ICC further identified adaptive and comprehensive command as the predominant command style that would best meet the demands of future complex missions. This approach enables CF commanders at all levels to operate in a decentralized manner and to exercise mission command (CFD 2009). Consistent with this perspective, the Chief of the Defence Staff 's Command and Control

[46] Chief of Force Development (CFD 2009), Integrated Capstone Concept, National Defence, Draft 24 September 2009

Operating Concept (VCDS 2012) provided a framework for the development of an agile and effective command and control capability that is also based on the concept of mission command. Accordingly, this framework assumes that future forces will be network-enabled with decision-makers highly distributed throughout the area of operations, all sharing situational awareness. In this concept of operations, commanders must make informed decisions that balance risk with the need for bold action and innovation, identifying their critical information requirements, and effectively communicating their intent. (VCDS, 2012)[47]. Timely decision-making, a central tenet of mission command, is thus a critical command function that focuses effort and enhances organizational agility.

2.15.2 Denmark

Since 2009 the Royal Danish Defence College (RDDC) has been engaged in the operationalization of agility with a special focus on managing complexity, sense-making, and the role of military intelligence in war fighting. With a considerable degree of inspiration and guidance from NATO SAS-050, 065, & 085, as well as the Command & Control Research Program, the Battlespace Agility concept, essentially the NATO SAS agility understanding placed directly within a NATO doctrinal understanding of war fighting only, at the Dept. of Joint Operations has been researched significantly with concrete results integrated into education. Over 4 years several projects have been executed in support of promoting greater agility in the battlespace, the largest of these included a 6 month intelligence project in Helmand Afghanistan under the auspices of Project Kitae I, II. More projects are forthcoming and a recent project, Project Crow's Nest was executed during the NATO Joint Warrior Exercise in the North Sea. It specifically examined the role of naval intelligence in battlespace agility will be written up in the later part of 2013.

Furthermore, since 2011, the NATO SAS agility conceptualization and the RDDC battlespace agility concept have been integrated and taught on various courses in Denmark including Senior Staff Courses, Advanced Joint Intelligence Courses, and operational planning courses. It is expected that over the next few years agility will become an even more integral part of how Denmark fulfills the current RDDC mandate stated in Danish as:

> "Gennem forskningsbaseret uddannelse i militære studier vil Forsvarsakademiet bidrage til, at forsvarets chefer kan kæmpe og vinde i morgendagens konflikter."

Translated into English it states that the RDDC is to provide a research based education to Defence Commanders as a contribution to supporting their ability to fight and win in future conflicts. Both the NATO SAS agility and RDDC battlespace agility research is already playing a visible and concrete role in fulfilling this mandate, including its application in actual war fighting operations.

[47] Vice Chief of the Defence Staff (VCDS 2012), Command and Control Operating Concept, June 2012

2.15.3 United Kingdom

In 2011, UK MOD sponsored a Command, Inform and Battlespace Management study (CIBM Task 10) to frame and contextualise C2 Agility in order to examine what needs to be addressed and what can be modified, added or sustained within UK capability development programmes.

Research over two years confirmed that practitioner views differ about what C2 agility means and how it can be achieved. Military practitioners have noted that general principles for tactical and operational successes and incremental improvements to C2 Agility will depend on wider enablers being in place[48] (e.g. building trust in capability) and any blockers (e.g. risk averseness) being reduced or removed.

To consider the implications across DOTMLPF[49] requires further engagement with models for change being suggested by the UK C2 Agility work, which involves seeing C2 as a socio-technical system. This demands use of cognitive, behavioural and socio-cultural factors in addition to the SAS-085 experimental factors, which were based mainly on information sharing structures and delegation of decision rights (e.g. military C2/HQ configurations, information sharing processes and corresponding CIS support). These new models for change generate the need for new C2 choices and compromises, which are concerned more with relationships than with connective network linkages. (For more detail see the Way Ahead subsection of Chapter 8. Findings, Conclusions, Way Ahead.)

2.15.4 United States

The US Chairman of the Joint Chiefs of Staff (JCS) recently issued a white paper[50] Entitled *Mission Command*, providing his view as to how C2 should be approached. Mission Command, as articulated in this white paper is an instantiation of SAS-085's concept of C2 Agility. The Chairman recognizes the need for a C2 Approach "toolkit" with appropriate approaches to C2 and also the importance of having agile individuals throughout the organization. Specifically, the white paper states that the "mission command requires adaptable leaders at every echelon." and that "Subordinate echelons must be allowed to own their own 'white space' and thereby develop unit cohesion and exercise judgment and creativity in training." There is also an explicit recognition of the need to resist the micromanagement that unfortunately can be enabled by improved communications and networking capabilities. "In a network-enabled force, the commander can easily penetrate to the lowest level of command and take over the fight. This is dangerous for a number of reasons. No C2 technology has ever successfully eliminated the fog of war, but it can create the illusion of perfect clarity from a distance. This can lead to micromanagement, a debilitating inhibitor of trust in the lower echelons of the force." Thus, the intent of the CJCS's vision of Mission Command is to have commanders move toward the edge corner of the C2 Approach Space as far as appropriate (given the mission and the circumstances). This involves allocating

[48] SAS-085 Hypotheses 11 and 12 have shown the need for the six enablers of agility (i.e. Flexibility, Versatility, Innovativeness, Responsiveness, Adaptability and Resilience. These need to be set within a broader Defence-wide set of enablers (e.g. having trust in capability and experience).

[49] DOTMLPF looks at lines of development across the domains of Doctrine, Organization, Training, Materiel, Leadership, Personnel and Facilities.

[50] CJCS, Mission Command, White Paper, 3 April 2012 http://www.jcs.mil//content/files/2012-04/042312114128_CJCS_Mission_Command_White_Paper_2012_a.pdf

decision rights to the greatest extent possible, accompanied by mission type orders. Thus, all things equal, the CJCS has directed US Commanders to move, in a balanced way, as far as they can along the three axes of the C2 Approach Space and no farther[51]. Thus, both C2 Agility and Mission Command involve the ability to maneuver in the C2 Approach Space.

2.15.5 Automation and Autonomy

The increasing deployment of autonomous systems, physical robots and virtual agents (decision being made by software agents or bots) creates a unique set of C2 challenges[52]. The CJCS Mission Command White Paper warns of the risks associated with micro-management which not only applies to the management of humans but also to a "bot force" that may be a part of someone's command. The number of intelligent agents could easily number in the 100s or thousands. Furthermore, there is an enormous difference in the time frames between human decision making and the decision making processes of intelligent agents. Understanding the implications of different C2 Approaches for 'robotic forces" is beyond the current state of the art. Thus, how to integrate real and bot forces is, currently, an open question[53].

The NATO NEC C2 Maturity Model describes a range of increasing network-enabled C2 Approaches that provide a foundation upon which C2 Agility can be built for both individual Entities and collections of Entities, both real and virtual.

This second chapter, ***Orientation*** has reviewed these and related concepts that SAS-085 has taken, as a point of departure, in our efforts to develop a more in-depth understanding of Agility, in general, and C2 Agility, in particular. The next chapter, **Chapter 3: BASICS OF AGILITY** as it is now understood by SAS-085.

51 The power of network enabled approaches to C2 derives from the ability to self-synchronize enabled by shared awareness and permitted by delegations of decision rights. This is the opposite of micromanagement which is also enabled by networks.

52 A popular discussion of how rapidly robots are entering the scene in military affairs is Peter W. Singer, Wired for War: the Robotics Revolution and Conflict in the 21st Century, Penguin, 2011.

53 53 At a more familiar level, however, consider the problem of C2 for last-ditch defensive systems such as on surface vessels. In some circumstances, effectiveness considerations may dictate autonomous operations. In more peaceful or ambiguous circumstances, however, man-in-the-loop command may be essential to minimize the risk of inappropriate weapon use.

Chapter 3 - BASICS OF AGILITY

"To improve is to change; to be perfect is to change often" *Winston Churchill*

This part of the final report is devoted to providing readers with an understanding of how SAS-085 defines Agility and the concepts that are intimately associated with it. As will be explained, SAS-085 sees Agility in two ways; as both an ***'outcome'***, and as a ***'capability'*** and provides a way of observing and measuring each. Agility as an 'outcome' can be observed when an Entity manifests Agility or, in some case, when an Entity fails to manifest Agility. Agility as a 'capability' represents a potential; measuring it requires an understanding of the characteristics, attributes, and behaviours that either enable or inhibit the manifestation of Agility when it is needed.

As SAS-085 moved from reviewing existing literature, to initial discussions about Agility, and to the development of an initial version of a conceptual model to using this model in experiments and case studies, we discovered some semantic disconnects that caused us to refine our model and our explanation of the model. By the time the first batch of experimental runs and case studies were completed, we became comfortable with how C2 Agility was defined and how we proposed it was observed in both real world situations and in simulated scenarios.

Agility, as SAS-065 understood it, is a meta-concept that encompasses a rich vocabulary of related concepts (e.g. flexibility, adaptability) that previously had not been "semantically de-conflicted." Dictionary definitions of the set of concepts SAS-085 considers to be facets of Agility are both inconsistent and ambiguous. For example, flexibility is equated with versatility[54] and adaptable with versatile[55] making it impossible to develop independent measures of these different Agility-related concepts in a way that permits them to be unambiguously and systematically observed. This state of semantic disarray mirrors the multiple ways these words are commonly used. Furthermore, different disciplines have appropriated one or more of these terms further mudding the waters. For example, Agility is equated with lean by some proponents of Lean Six Sigma, who seek to optimize processes. When processes are optimized for a particular set of circumstances, they arguably have an increased likelihood of not working acceptably when the situation changes[56]. Thus, a quest for leanness may result in the opposite of Agility, that is, fragility. Dodd and Hilton note that "There seems to be an Agility paradox as the meaning of agile (termed also as "lean" originally) has diverged to suit the forms of business into which Agility concepts have been adopted. On the one hand there is the customer-focused, managed business for profit and the fight for survival in competitive markets that places a performance perspective on having the agile/lean concept mean efficient, cost-minimal, rapid response, maximum profit,

[54] "He shows remarkable flexibility as an actor. [=he can play a wide range of roles]" Webster http://www.learnersdictionary.com/search/flexible

55 Versatile is given as the first synonym for adaptable http://www.merriam-webster.com/dictionary/adaptable

56 For example, efficiencies often come at the expense of built-in slack and redundancies that serve to allow entities to cope with disruptions and other stresses.

etc. On the other hand there is Agility through leadership, which has respect and allows space for individual ability and exercising of judgment." [57]

SAS-085 devoted a considerable amount of time to putting on the table the various views of Agility held by members and those found in the literature in order to reach a consensus on a working definition of C2 Agility that would be used as the basis of the C2 Agility Conceptual Model and effects to validate this model. Given that various terms related to Agility were defined differently, sometimes interchangeably, the choice of what label to use for which concept is arbitrary. SAS-085 did not start from scratch but built upon the work of previous SAS Research Groups[58] and the C2 Research literature since our primary audience is NATO, particularly those who are involved in the art and science of military operations and/or the systems and technologies that support these operations. We urge readers who define these terms differently to look past the label to the idea itself. In this way they should be able to see if the substance of our work makes sense to them rather than get lost in semantics.

Since SAS-085's interest in Agility is practical in nature, we focused the majority of our attention on the implications of Agility for C2. Specifically, on what it means to have approaches to C2 that are agile and how agile approaches and the ability to employ these approaches appropriately translates into an operational capability that increases both potential and manifested Agility. Questions to be asked included whether or not one could observe and measure variables related to C2 Agility, understand their impact on measures of mission performance and hence the value of increased C2 Agility. The ability to observe and measure C2 Agility is required if we are to improve the C2 Agility of our organizations.

Readers who are interested in learning more about the ways in which Agility is viewed by others are encouraged to turn to the source materials cited for more in-depth explanations and discussion.

3.1 DEFINITION OF AGILITY

The idea of Agility as a key C2-related concept / capability that required an agreed upon definition for the C2 community and systematic exploration in the context of network enabled C2 emerged almost a decade ago in discussions between U.S. and UK researchers and analysts[59]. These discussions grew to include colleagues from Australia, Sweden, Canada and ultimately the set of countries that have participated in the set of NATO SAS Research Groups that have preceded SAS-085. The initial focus of these discussions was on identifying the set of words that are used in the vernacular and choosing one of these words to stand for this set of ideas. Having chosen Agility to be the "headline" term, attention was focused on developing simple, disambiguated definitions for the terms encompassed by Agility (the enablers) and the relationships between and among these enablers. SAS-085 having the results of this work available, noted that the "definition" of Agility provided consisted only of a set of Agility-related terms, an implicit definition. While there was general

[57] Dodd and Hilton CIBM Programme: Task 10 C2 Agility, Work Package 1: Top-down review of current Agility research, Sub-package WP1.1: Academic Literature Review, Final Draft of Internal Working Paper, 14th November 2011, Cranfield University, Defence Academy of UK

[58] SAS-050 that produced the NATO C2 Conceptual Reference model http://www.dodccrp.org/files/SAS-050%20Final%20Report.pdf and SAS-065 that produced the NATO NEC C2 Maturity Model http://www.dodccrp.org/files/N2C2M2_web_optimized.pdf

[59] See the acknowledgement section of Alberts, D. S. and Hayes, R.E., Power to the Edge, DoD CCRP Publications Series, Washington, D.C. 2003

agreement among SAS-085 members that the six enablers of Agility (responsiveness, robustness[60], flexibility, resilience, adaptability, and innovation)[61] did a good job of capturing the idea, they felt that a definition that went beyond a list of enablers was needed to provide a basis for ascertaining whether or not these six were individually necessary and collectively exhaustive. That is, does each of the six add something and do the six, taken together, cover all of the aspects of Agility?

The simple definition, presented in the introduction requires additional specificity, if it is to be used to guide observation and measurement. Thus, each of the key terms in the previously introduced definition of Agility is further described below:

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

Where:

Successfully is defined as operating within acceptable bounds. This includes defining the significance of "out of bounds performance" as a function of both magnitude (how far) and duration (how long).

Change in Circumstances, as we use the term, includes changes to the State of the Other Entities and the Environment and/or to the State of Self. These changes are not restricted to the physical domain, but also include changes to variables in the Information, Cognitive, and Social domains as well. . Further, in this context, changes of circumstances include changes of mission, strategy, or objectives within them. [62]

Effect implies being proactive and therefore able to bring about a change in circumstances in order to improve performance, effectiveness or efficiency. . [63]

Cope with implies dealing with one or more of the above changes in circumstances that, if not appropriately addressed, would adversely affect performance (effectiveness and efficiency).

60Robustness was found to create some semantic difficulties as this term had quite different connotations for different communities. SAS-085 decided to use the term 'versatility' instead since it appeared to present less of a problem.

61 These terms were identified as "aspects" of Agility. See Chapter 8, Alberts, D. S. and Hayes, R.E., Power to the Edge, DoD CCRP Publications Series, Washington, D.C. 2003 identifies these six aspects of Agility , provides short descriptions of each as well as some examples.

62 Often, people use "circumstances" to mean aspects of state other than those of "self." Our definition has advantages and disadvantages. Among the advantages is that is makes it clear that it is important to understand how changes to Other Entities and the Environment affect Self but also understand how changes to Self affect Other Entities.

63 Timeliness is implicit in our definition of Agility, since the actions and entity takes (effect, cope, exploit) need to be successful and thus need to be accomplished in a timely manner.

Exploit implies capitalizing on an opportunity to take advantage of changed circumstances that if not seized, would result in an opportunity loss (a failure to improve performance – improve effectiveness or efficiency or both).

This definition provided the basis for SAS-085's exploration of the concept of Agility as it applies to the C2 of military forces in the context of Complex Endeavours that ultimately resulted in the conceptual model presented in the next part of this report. This part of the report is devoted to some of the basic ideas associated with Agility and its application to C2.

3.2 ENABLERS OF AGILITY[64]

Seen as ways to improve Agility, the following six enablers were first introduced into the literature circa 2003 as aspects of Agility. SAS-085 used, as its point of departure, the definitions for these terms adopted by SAS-065[65] as previously indicated.

Responsiveness

Versatility[66]

Flexibility

Resilience

Innovativeness

Adaptability

Agility is the dependent variable of interest while these enablers are variables that Entities seek to control[67] in order to realize the amount of Agility they desire. These enablers are ***not independent*** of one another. In fact, these interdependencies are a matter of interest to SAS-085.

In this report, SAS-085 has chosen to use the term "enabler" to refer to these six variables. This was the result of considerable discussion among the members of SAS-085. In addition to the term "enabler" other terms, including: components, attributes, characteristics and aspects of Agility were considered. For a while, the term component was a leading contender, but was ultimately rejected because of its connotation of decomposition. We sought a term that would recognize the inherent interdependence among this set of

64 See Chapter 14 in The Agility Advantage for a more detailed discussion.

65 SAS-065 produced Version 2.0 of the NATO C2 Conceptual Reference Model. This version of the model provides definitions for these Enablers of Agility.

66 Originally called Robustness, SAS-085 re-labelled this enabler to avoid confusion with usage in other disciplines where robustness means resistance to shock or insensitivity to assumptions

67 The term controllable variable is commonly used to denote that which is subject to control in an experiment. The experimental treatments are, in fact, specific values for one or more controllable variables. SAS-085 recognizes that control, in real world situations, particularly in the context of Complex Endeavours, may not be an attainable goal. SAS-085 thus uses this term to refer to variables that may be directly or indirectly be influenced.

variables and the fact that their contributions are collective in nature and are not individual ones. For example, flexibility without responsiveness does not enhance Agility and flexibility and resilience are, on occasions, mutually re-enforcing.

The term "enabler" is not without its problems. Of particular concern was that some may interpret an enabler as a variable that should be maximized. That is, the more of an enabler an Entity possesses, the more agile the Entity becomes regardless of how much Agility / flexibility it already possesses. However, these six enablers of Agility are not unmitigated goods[68]. Figure 3.1: Agility as a Function of Flexibility, depicts the relationship between Potential Flexibility and Agility.

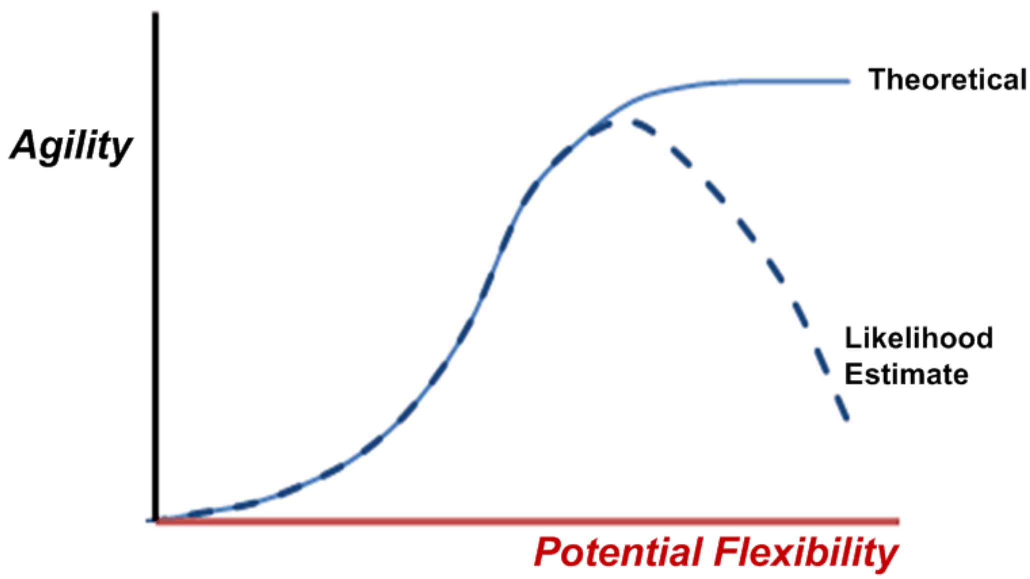


Figure 3.1: Agility is a function of Flexibility

Recall that potential flexibility is defined as having more than one way to achieve a desired result. The solid line depicts the case where an Entity only uses the Flexibility that is needed and chooses easily among its options in a timely manner. Having options becomes important if the preferred way cannot be exercised, does not work given the circumstances, or becomes prohibitively costly. In theory, the more options one has, the more likely it is that one will have a good option available whatever the circumstances. Furthermore, in theory, the Entity can make the correct choice among the options in a timely manner and adequately execute

68 Not diminished or reduced in its impact or value

the selected option. Even so, as the number of options in one's toolkit increases, the marginal contribution of each additional option gets smaller (the law of diminishing returns). This is why the solid line does not increase beyond a certain point and levels off.

If too many options are considered, an Entity may become indecisive, slow to respond, or error prone. As a practical matter, it becomes increasingly challenging for an Entity to master and correctly choose among the alternatives as the number of available options increases. The dashed line takes into consideration these realities, including less than perfect choices, the inability to be equally proficient across a set of options, and the opportunity costs associated with developing and maintaining a toolkit as the number of tools increases. Thus, in practice, having more options does not always translate into improvements, and, can actually make things worse.

Flexibility, whether one looks at it from a theoretical or practical perspective, is not something that should necessarily be maximized. As with Agility, (see discussion in ***Chapter 2: Orientation)***, there is an appropriate amount that an Entity requires of each of these enablers; in this case, requisite flexibility. The appropriate amount of flexibility an Entity should possess depends upon, among other things, the degree to which it possesses each of the other enablers. Thus, there are tradeoffs between and among the enablers of Agility that make a determination of the requisite amount of each enabler somewhat complicated. Figure 3.2, Requisite Agility and Flexibility, depicts the relationship between Requisite Agility and Requisite Flexibility, given specific levels of the other five enablers the Entity possesses.

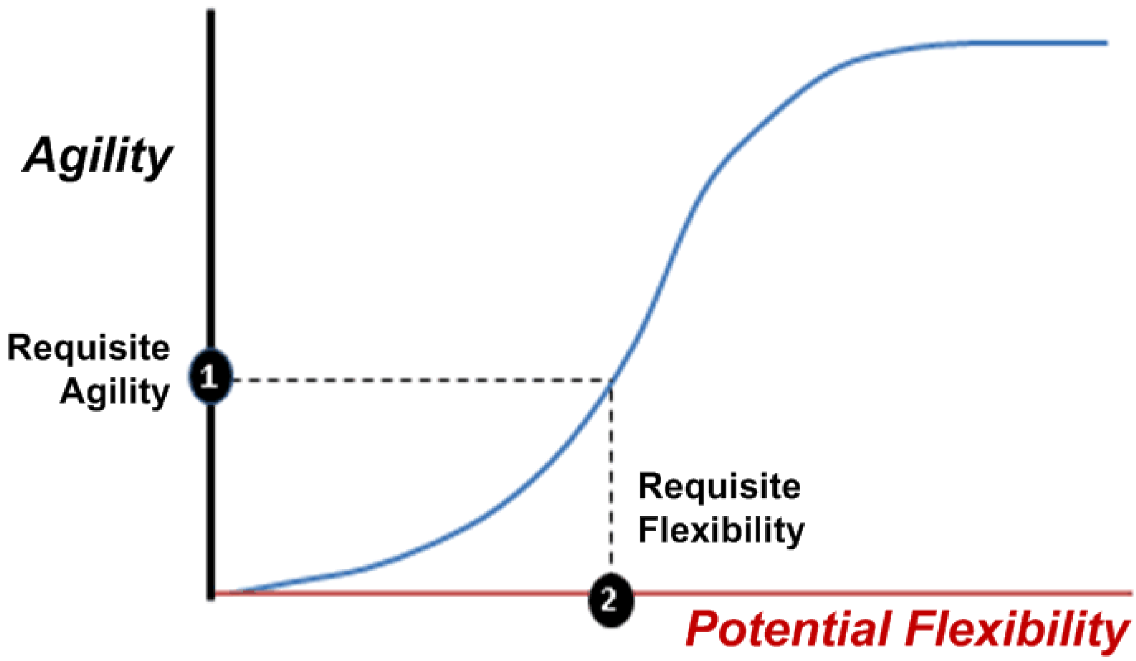


Figure 3.2, Requisite Agility and Flexibility

Figure 3.3, Requisite Flexibility as a function of Resilience, depicts the impact of resilience. Two curves are shown, one for the case where an Entity possesses high resilience and another where an Entity's resilience is low (all other factors affecting Agility are held constant). For each of the two resilience capabilities, the relationship between the amount of flexibility an Entity has and its Agility, as well as where Requisite Flexibility would be found on the flexibility scale is depicted. One can see that the shapes of the curves, as well as the position of Requisite Flexibility on a scale of flexibility differ as a function of resilience. In this case, resilience contributes to the value of having flexibility by enhancing its impact on Agility.

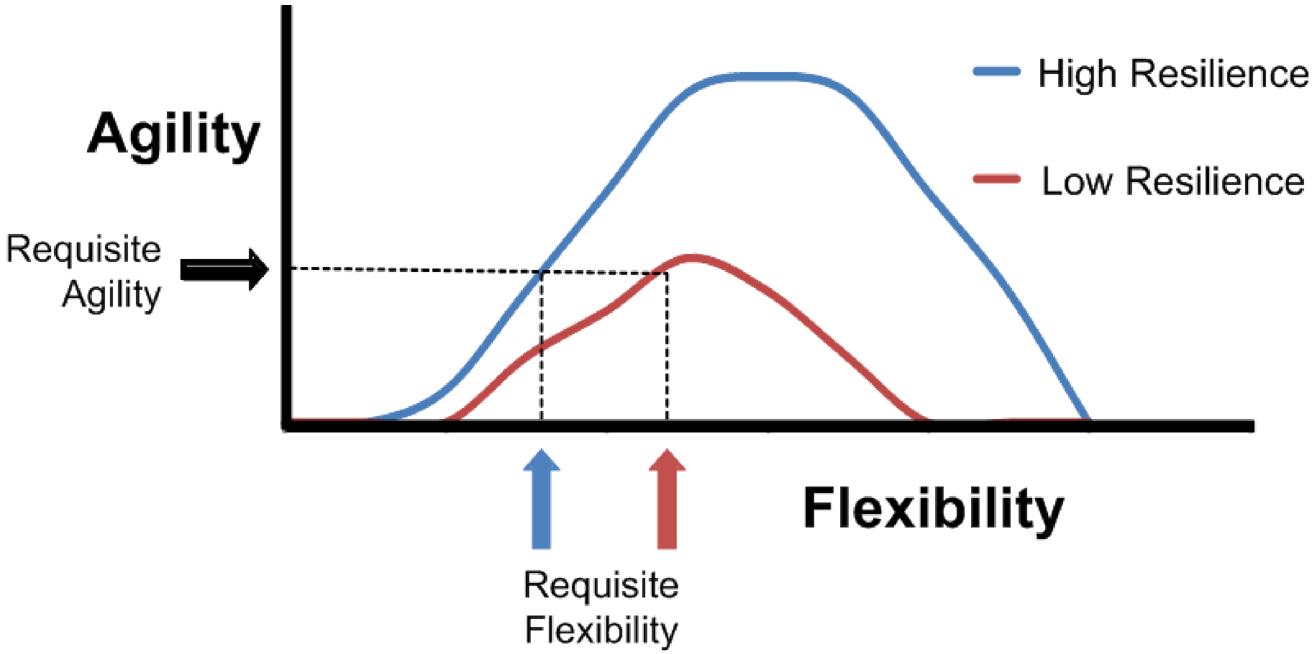


Figure 3.3: Requisite Flexibility as a function of Resilience

Responsiveness matters when a response to a change of circumstances is required. Being responsive is simply a matter of being able to react in a timely manner. This is a function of when one is able to accomplish the tasks required to take action and the time it takes for the action(s) to have an effect. This includes when, relative to the change in question, a need for a response is recognized (in anticipation or in reaction to an event), when an appropriate response is determined, and when the necessary actions can be taken.

But responsiveness alone, does not guarantee that an Entity will manifest Agility, that is, be successful. To be successful, one not only has to be responsive, but also the actions taken need to have the intended result. That is, actions must enable the Entity to keep performance within acceptable bounds, to return to an acceptable level of performance, or to improve effectiveness and/or efficiency so that resources expended can be reduced. Four of the enablers of Agility -- flexibility, resilience, innovativeness and adaptability each and in combination address different kinds of stresses or provide various means to respond to changes in circumstances. For example, *flexibility* provides more than one way of accomplishing something. Thus, if the current approach is rendered ineffectual or too expensive as a result of a change in circumstance, flexibility offers at least one alternative.

Responsiveness, flexibility, innovation, and adaptability are all “active” and involve orchestrating a response. In contrast, *Versatility* requires no response. The following discussion, found in The Agility Advantage,[69] serves to illustrate this point.

69 Alberts, D. S. The Agility Advantage

"an Entity may possess a set of characteristics that makes it possible for that Entity to successfully cope with a set of changes without taking action. That is, under certain circumstances, a change in Entity behaviour may not be necessary to exhibit Agility. Thus, Agility has enablers that are both passive and active. Passive Agility involves characteristics that allow the Entity to continue to continue to operate effectively without taking any action, despite some changes in circumstances or conditions. An example of this passive quality is versatility. Looking at Figure 3.4, Versatility of Screws, we see three screws. The one on the left can only be used with a normal or slotted screwdriver, the one in the middle requires a Phillips head screwdriver, and the one on the right can be used with either one"[70].

Figure 3.4, Versatility of Screws

Innovativeness involves creating something new, e.g. a new ways of accomplishing something in the event that current practice does not provide adequate capability or performance. While flexibility refers to having more than one choice, innovativeness adds new ways and means to the toolkit. Adaptability refers to making changes to Self in anticipation of or response to changes in the environment. In this case, it is not what one does that needs to change, but what one is and how one operates. Thus, adaptability could involve changes in coalition membership, organization and/or processes.

Resilience can be either passive or active or both. Resilience pertains to changes that damage or degrade an Entity. Being resilient involves an ability to maintain performance within acceptable bounds despite suffering

70 The Agility Advantage p.192 and Figure IV-1.

damage. Being resilient may require that some action be taken (e.g. bring some offline capability on-line) or it may require no action be taken (e.g. existing redundancies provide the protection needed). For example, an appropriately designed network can still provide acceptable services in the event a number of links goes down.

There are numerous ways these enablers could interact, creating synergies that enhance an Entity's Agility[71]. As mentioned above, innovativeness and flexibility have some obvious interactions. Innovativeness makes it possible to create new options to add to one's toolkit, while flexibility enables Entities to take full advantage of the available options (having options in the toolkit is not an end unto itself). Responsiveness interacts with a number of enablers. One way to be more responsive is to anticipate changes rather than wait for an event to be detected. If one is able to do this, then the time available to mount a response increases. Having more time available may mean that some options that were not feasible because they took too much time to implement or took too much time to create effects may become feasible, increasing flexibility. More time may also provide an opportunity for increased innovativeness.

SAS-085 considered, as part of its consolidated analysis of case study and experimentation results, whether this list of six enablers needed to be modified or extended. That is, SAS-085 case studies considered whether or not this list is sufficient to describe how Entities actually manifested Agility or, in the case where Entities failed to respond appropriately to changes in circumstances, whether or not this list is sufficient to attribute this failure to a lack or deficiency in one or more of these enablers.

3.3 AGILITY VALUE CHAIN

In SAS-085's C2ACM, the enablers of Agility are part of an "Agility Value Chain" that includes the set of links that connects various Entity characteristics and behaviours to Entity Agility. Figure 3.5, Agility Value Chain, depicts Agility to be a function of both Self and the challenges associated with the mission and environment.

[71] See The Agility Advantage pp.219-221

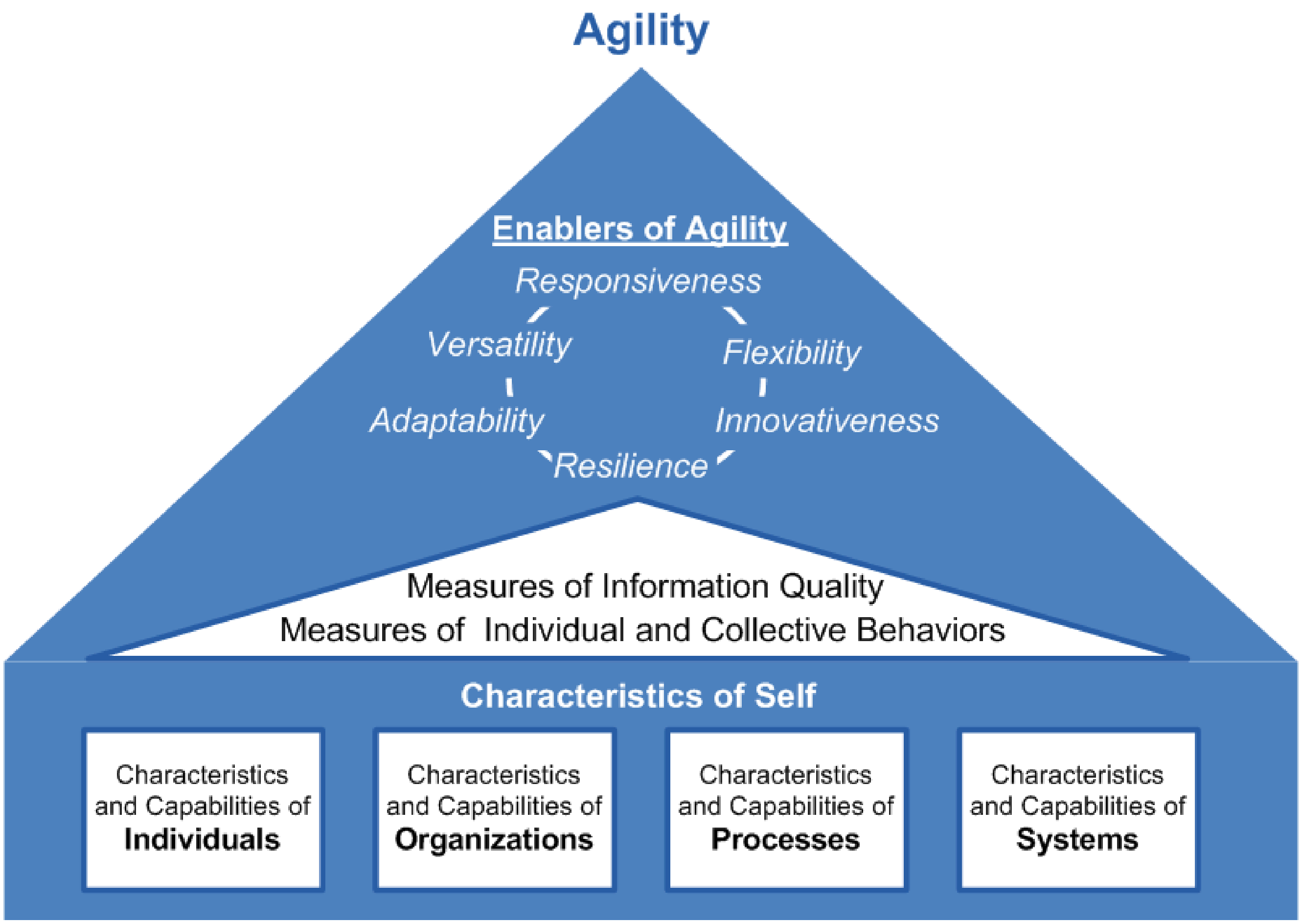


Figure 3.5 Agility Value Chain

Thus, Agility is a function of its enablers which, in turn, are determined by the quality of information and behaviours that result from the characteristics of Self and the nature of the Endeavour Space. From Figure 3.5 one can see that the Agility Value Chain is not a simply a string of links, but is in reality a mesh or network of interdependent variables.

3.4 RECOGNIZING AND MEASURING AGILITY

Operationalizing Agility, that is, moving Agility from a desire to a capability, from a theory to a practice, requires that we are able to:

- Observe Agility or a lack of Agility.
- Measure the degree to which Agility is manifested by an Entity in a particular situation.
- Estimate the degree of effectiveness that an Entity will manifest in a particular situation (mission and circumstances).
- Estimate an Entity's Agility potential with respect to an Endeavour Space that captures the set of relevant missions and circumstances.

The ability to make these observations and measurements will enable us to assess our current state of Agility, compare the Agility of two or more Entities (or the same Entity with different capabilities) and understand how to improve Agility.

SAS-085 devoted the bulk of its time and energy to conducting a series of simulation based experiments and undertaking a set of case studies in a quest for answers to the following questions:

- Can we observe agile behaviours, or the lack thereof?
- Can we observe the consequences of these behaviours?
- Can we determine the value of the Agility that is or is not manifest?
- Are metrics available that provide quantitative measures of the Agility of a specific C2 Approach?
- If an Entity can employ more than one C2 Approach, how does this change its Agility?
- How does one measure the Agility of a C2 system?
- Do we have a way of measuring Potential Agility?
- Do we have the theory and tools we need to provide insights that we can use to improve C2 Agility?

As will be explained in detail later in this report, SAS-085 was able to collect evidence that addressed many of these questions as a result of its validation efforts. We have found that SAS-085's simple definition of Agility prepares us to recognize situations that may require Agility, enables us to recognize Agility when we see it, and suggests a way to measure Agility or the absence of Agility.

The first thing the reader may note is that the concept of Agility is linked to the existence of a change[72] that either threatens success or provides an opportunity to be more successful. As defined, the capability we call Agility (or a lack of this capability) can only be directly observed if and when a change of significance actually

[72] SAS-085 considers a change in perception to constitute a change that may be as relevant as a change to 'ground truth.'

takes place. When something changes, there is an opportunity to observe the Agility that is manifested or note its absence. In situations where there is no possibility or prospects of change, the concept of Agility, as SAS-085 defines it, does not apply.

Change creates a new reality that can be compared to what would have happened if the change had not occurred. It is in the differences between these alternate realities, that we can find a measure of the value of Agility. The first of these realities, what would have occurred had no change taken place, serves as our baseline. The second of these realities is what actually takes place when a change occurs, that is, the response or lack of a response to the change. The degree to which an Entity possesses Agility is a function of its ability to sense (or anticipate) and respond to change. Thus, in order to observe Agility one needs to monitor both 1) the set of variables associated with circumstances to note when a change takes place, and 2) the measure(s) of success to see the impact that the change has and the effectiveness of the response.

Given a change with the potential to adversely impact the measure of success, there are four possible outcomes that could occur and can be observed. These four outcomes are as follows:

- The performance of the Entity remains within acceptable bounds without any response being required or taken. Thus no response is required.
- A response is required, the Entity responds and performance remains within acceptable bounds.
- A response is required, the Entity responds, performance does not remain within acceptable bounds for a period of time after which it returns to within acceptable bounds.
- A response is required and performance never returns to within acceptable bounds.

Given a change that offers an opportunity to improve our measure of success, the following outcomes can occur:

- The opportunity is not recognized
- The opportunity is recognized and a response is taken but performance is not improved.
- The opportunity is recognized, a response is taken, and performance is improved.

3.5 EXAMPLES OF AGILITY OR A LACK THEREOF

Each of these six outcomes tells us something about the Agility that is or is not manifested by the Entity and the value of being or not being agile. Outcomes 4 and 5 are examples of a lack of Agility. Outcome 1 is an example of manifest Agility and indicates that the Entity in question possesses the passive Agility enabler Versatility. Outcomes 2 and 6 are examples of manifest Agility and indicate that the Entity possesses adequate Responsiveness. However, without additional information we cannot associate the Agility manifested with any specific enablers of Agility. Outcome 3 is an example of a degree of Agility and its value can be measured by the magnitude of the loss in effectiveness and/or efficiency (relative to the baseline) and the time it takes to restore these measures to a level that has been defined to be satisfactory. This discussion and the related figures treat the measure of value as a scalar. A discussion of multi-criteria effectiveness measures is provided in the next section.

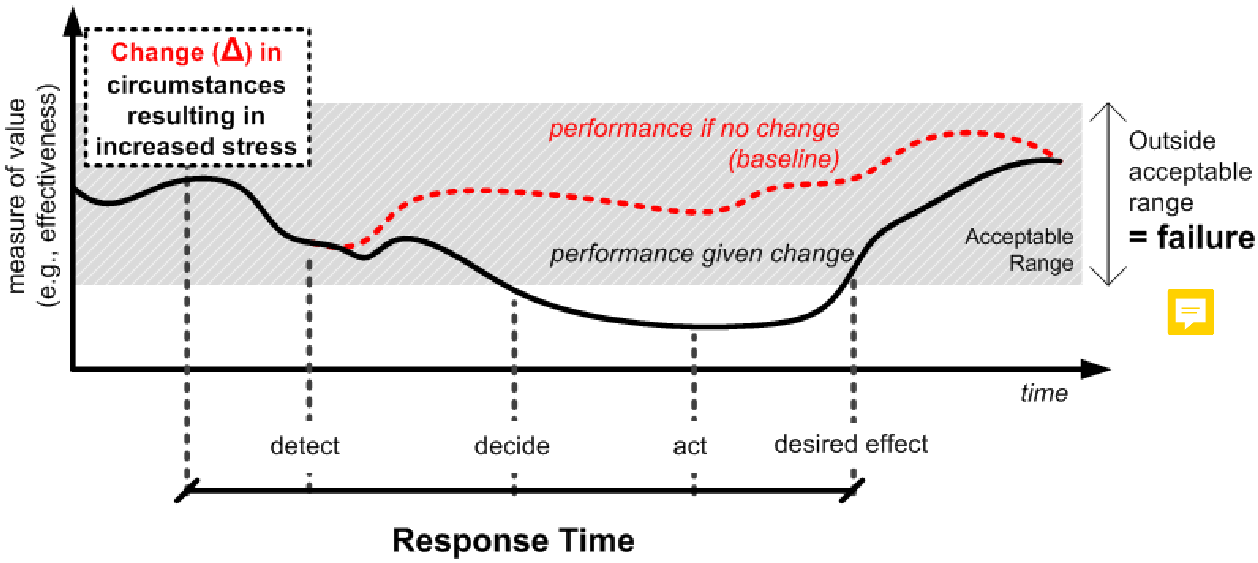


Figure 3.6: Example of a Lack of Agility

This situation is depicted in Figure 3.6: Example of a Lack of Agility [73] which involves an event that has had, after some delay, an adverse impact that results in an unsatisfactory level of performance, an outcome that indicates some lack of Agility.

The event is detected at the time performance became unsatisfactory. After some period of time, a response is decided upon, and after some delay, action is taken. The measure of value is ultimately restored to a value that is within the acceptable range. However, because performance has not remained in the acceptable range, the Entity has not displayed sufficient responsiveness.

The solid black line depicts actual performance levels over time. The red dotted line depicts performance levels that would have occurred had the event not taken place (serves as a baseline). The difference (area) between these two lines is the consequence of the Entity's Agility, or as in this case, a lack of Agility. Translating this area into a measure of value is context dependent. In analyzing the significance of the size / shape of this area, the part of the area within acceptable bounds should be treated differently than the part of the area that is outside of the acceptable bounds.

Readers can imagine how the area between these curves would change if the Entity's responsiveness could have improved. For example, the time between detection and action were reduced or if the event was anticipated and a response was initiated prior to the event actually occurring. Another way to improve the Agility manifested here would be to reduce the time it takes for a response to have the desired effect. Figure 3.7: Result of Reduced Time to Respond, depicts the consequences that a reduction in the time to respond (the time between the event and the restoration of performance to within acceptable bounds) would have on the

[73] Adapted from Figure IV-6, The Agility Advantage

area between the curves. In this case, the reduced response time (Agility manifested) mitigates the adverse impact of the change so that the measure of success never goes outside of the acceptable range.

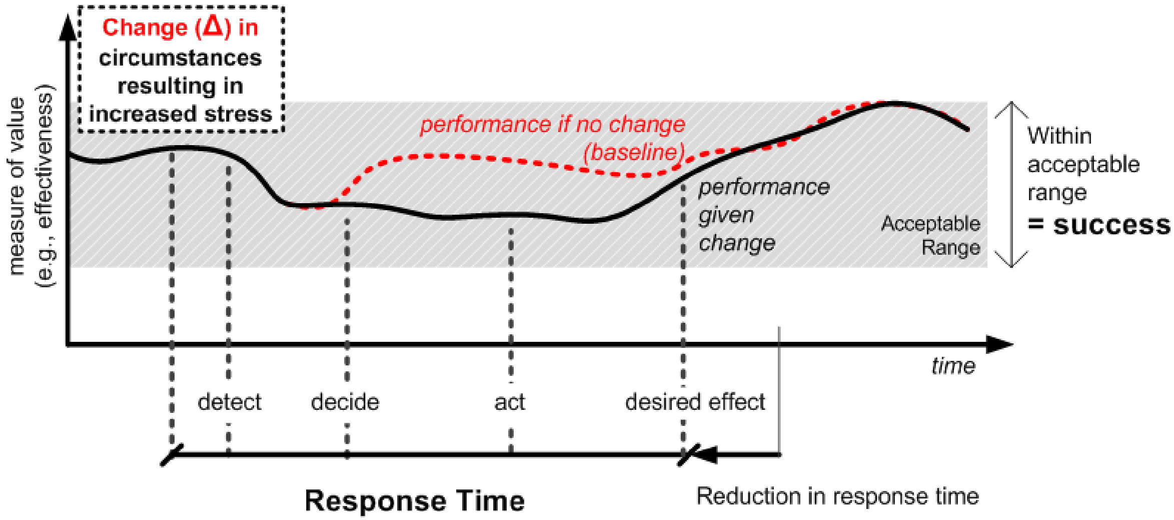


Figure 3.7: Result of Reduced Time to Respond

3.6 GENERALIZATION TO MULTI CRITERIA EFFECTIVENESS MEASURES

It is often not possible or appropriate to measure effectiveness as a scalar. The literature on policy analysis and strategic planning, for example, concludes that effectiveness is best depicted for each of the problem's major objectives (much as normal people often want to compare options with a multi-criteria scorecard rather than by just a list of someone's aggregate numbers). Combining (aggregating) effectiveness scores across components is fraught with dangers and is often best deferred until *after* the most important decisions, at which point a one-dimensional simplification can be used for communication and for fine tuning.[74]

To be less abstract and relate the issue to C2 for complex endeavors, suppose that ultimate success in a complex endeavor such as a multinational intervention depends on achieving a sufficient level of military success, political success, economic success, and even sociological success. Overall effectiveness would be some nonlinear function of the component effectiveness: failure of any one could mean failure overall. Exactly what this value function should be is, however, highly subjective and different entities would weigh success on

74 These matters are discussed in the context of portfolio analysis in defense planning in Paul K. Davis, Russell D. Shaver, and Justin Beck (2008), Portfolio Analysis Methods for Assessing Capability Options (Santa Monica, RAND). The mathematics of dealing with multi-criteria effectiveness are discussed in Paul K. Davis and Paul Dreyer (2009), RAND's Portfolio Analysis Tool (PAT) (Santa Monica, Calif., RAND). The work was done for an Under Secretary of Defense. A simpler analogue that may be useful to readers is recognizing that the "effectiveness" of a retiree's investment portfolio cannot be measured in terms of its expected yield along. As a minimum, effectiveness also depends on the risks posed by the portfolio. If one insists on a single aggregate measure, accounting for both expected yield and risk, that measure will necessarily depend on the particular individual's situation and cannot be something simple such as, say, the average of a measure for yield and a measure for risk.

these different dimensions differently and favor differ tradeoffs between and among success on one of these dimensions versus another.

The admonition here for C2 Agility is that one should probably construct separate plots akin to Figure 3.6 for each of the major components of effectiveness. For simplicity, we ignore such complications in most of this report, but they will be important in applications.

3.7 MANIFEST VS. POTENTIAL AGILITY

The approach discussed above is based upon observing the Agility that is actually manifested by a particular Entity in a particular circumstance. A baseline needs to be established to serve as a benchmark. Because it relies on specific events and response scenarios, this approach is based on looking at one or more samples from the set of possible events.

Some events that are possible, even probable, may not take place during a particular endeavour or if they do take place, the consequences (a change in circumstances) may not rise to a level of significance. It is important that Entities do not confine their Agility (or preparedness) assessments to the events that may have actually occurred and their responses to these events. This limits these assessments to hindsight and focuses attention on and preparation for event(s) that have occurred, ignoring those that have yet to occur.

This raises the question of how to assess Agility before it is manifested in actual operations, that is, how can we assess Potential Agility? There are two basic ways of approaching this assessment challenge. The first and most common approach is to imagine what is likely to occur and, using simulation and analysis, predict what the impact on effectiveness and efficiency would be if these events took place. Being able to predict the future has the added benefit of being able to focus all one's attention on preparing for it and we would expect that we would observe a high degree of Agility as anticipated events would be effectively responded to in a timely manner. History, of course, does not tell this story, rather history indicates that we face unanticipated circumstances for which we are more likely to be ill-prepared than not. The lesson SAS-085 takes away is that one needs to be able to deal with unexpected and unfamiliar circumstances. In other words, Entities need to prepare without knowing the specific events to prepare for.

3.8 ENDEAVOUR SPACE

Two approaches could be employed to prepare for the future without the benefit of "point predictions". The first approach is to consider a set of test cases that represent the kinds of things that could occur and prepare for situations that possess the challenges associated with these test cases, not the cases themselves. Thus, the test cases are not to be taken literally but rather as instantiations of classes of events or circumstances. This more systematic way of thinking about the possible changes in circumstances that may confront an Entity in the future involves the creation of an Endeavour Space.

The creation of an Endeavour Space is analogous to the conceptualization of the C2 Approach Space in the sense that they are efforts to identify variables that are significant, variables whose values will determine choices. The C2 Approach Space was developed by thinking about what made one C2 Approach different from another. In the case of the Endeavour Space, we need to identify and characterize the missions and circumstances (including the environments and conditions) that could plausibly[75] occur, and the dynamics associated with them rather than simply develop a list of specific events or scenarios that are considered to be likely. Such a list when used to focus analysis amounts to a set of point predictions.

With this in mind, SAS-085 began by looking at potentially significant changes to both the current mission environment and to "Self." The question SAS-085 posed was how these changes to the status quo could affect the effectiveness and/or efficiency of the C2 Approach being employed. The two lists provided below are meant to be illustrative. They are intended to seed a discussion of the dimensions of Endeavour Space.

3.8.1 Changes to Self:

- A modification in the criteria by which an Entity determines value.
- Changes to acceptable bounds of performance (e.g. definition of mission success, constraints imposed on force employment or rules of engagement).
- Added or lost capability of Self (e.g. deployment of a secure collaboration capability or the introduction of a disruptive technology).
- A degradation of system performance caused by physical damage, cyber-attack or some system failure that adversely affects performance (reduces one's ability to perform tasks).
- A modification in the composition of a Coalition or Collective (e.g. adding a new partner).
- A breach of information security (e.g. discovery of a Trojan horse).
- A loss of agreement or shared awareness among mission partners.
- A loss of trust in information, information sources, partners.

3.8.2 Changes to Mission / Environment

- Different capability of an adversary (e.g. a new tactic, a new disruptive technology or capability such as an offensive cyber capability).
- Different composition of the adversary (e.g. loss of an ally).
- Different operating conditions (e.g. terrain, weather.)
- Changes in public perceptions of success and/or prospects of success.
- A new or emerging threat (e.g. change in Government from friendly or neutral to adversary).
- Change in mission scope and/or in the conditions on the ground (e.g. the loss of a permissive environment or the outbreak of disease which would make the problem more challenging).
- Change to the time available to accomplish a task (e.g. damage to an adversary that delays a planned attack).

[75] The definition or formulation of an Endeavour Space is a critical element of any analysis of Agility. On the one hand, one can easily err by relying too much on conventional wisdom or "approved" scenarios and, thus, construct an endeavour Space that is too small, one that omits futures that should be considered. On the other hand, one can include every conceivable eventuality and thus construct an Endeavour Space that is too large. In the first instance, Agility will be over-estimated, while in the second instance, Agility will be under-estimated.

3.9 ENDEAVOUR SPACE AGILITY MAP AND METRICS

The Endeavour Space represents, in the form of their characteristics, the set of alternative futures; the circumstances in which an Entity could find itself. At a given point in time, an Entity will be located at one point in this space. However, in a dynamic environment this situation is likely to change sooner or later relocating the Entity to elsewhere in the Endeavour Space. Agility means that an Entity will continue to be successful despite changes to its Self or its environment, even when some of these changes cannot be predicted with confidence. The degree of Agility can be visualized, as depicted in Figure 3.8: Illustrative Agility Map.

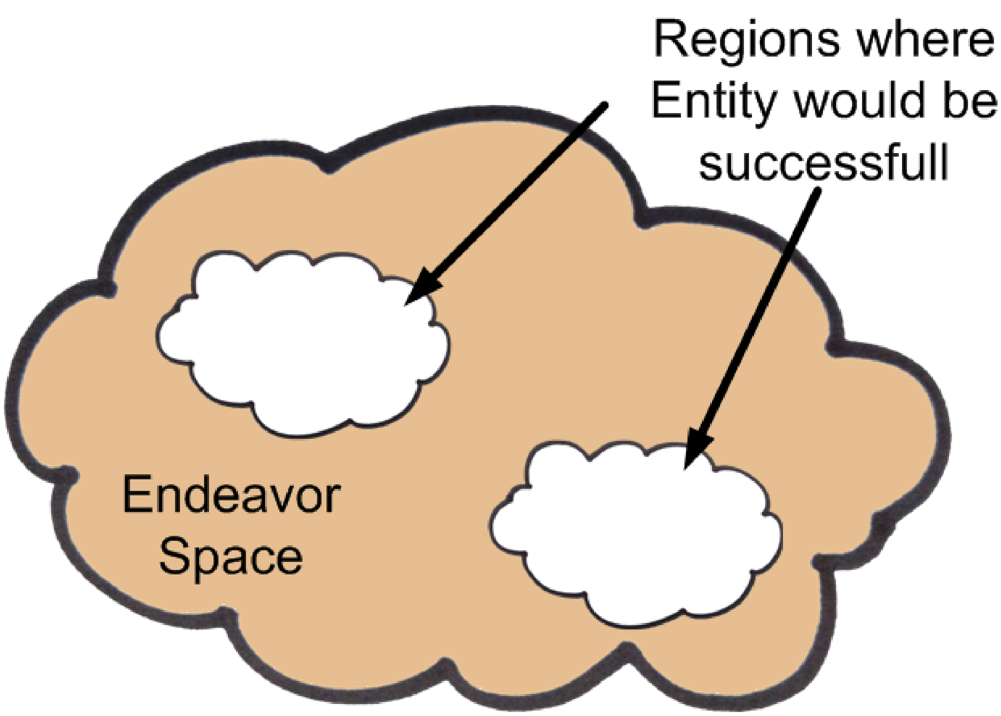


Figure 3.8: Illustrative Agility Map

As previously discussed, the degree of Agility an Entity possesses can sometimes be expressed in a scalar metric. Two such Agility metrics, a simple measure and a benchmarked measure, have been previously described and illustrated.[76] Both are based upon an Endeavour Space. If an Entity were perfectly agile, then it

[76] Alberts, D. S. The Agility Advantage p. 424-45; and Alberts, D. S. and Manso, M. Operationalizing and Improving C2 Agility: Lessons from Experimentation, 17th ICCRTS and Manso, M. Measuring Agility in ELICIT

could operate successfully anywhere in this space, that is be successful when faced with missions and circumstances whose characteristics are contained in the Endeavor Space. The greater the region in this space where an Entity would be successful the more agile it would be. This leads to a very simple measure of Agility - the percentage of volume in Endeavour Space where the Entity can be successful. [77].

In applying this measure to an Entity, both the definition of the Endeavour Space and the interpretation of the value of the metric are critical. In particular, care must be taken in defining Endeavour Space. The tendency is to equate Endeavour Space with existing planning scenarios or test cases despite the fact that past experiences have shown that these often exclude important circumstances that actually occur and when they occur they appear as surprises[78]. Furthermore, they invariably focus attention on relatively few cases and encourage "optimization", which is antithetical to Agility. If the Endeavour Space is too narrowly defined, then it is more likely that the Agility metric will over-estimate an Entity's Agility and needs to be interpreted with this in mind. Likewise if the Endeavour Space is too broadly defined, the result will be to under-estimate Agility. The first may result in investment patterns that leave the Entity unprepared while the latter may result in a waste of resources.

The benchmarked measure of Agility is based upon a "normal" set of circumstances, a specific region within Endeavour Space. The performance of the Entity under these circumstances constitutes a baseline. If an Entity can maintain this level of performance through the Endeavour Space the Entity would be considered to be completely agile and the value of this metric would be equal to 1. This is the same as with the simple measure. If the Entity is only successful under "normal" conditions then its Agility would be equal to 0. This is less than the value that would be calculated for the simple measure. For Agility values in between, the performance of the Entity is compared to the baseline to determine if Entity performance is degraded regions

[77] Clearly all points in Endeavor Space are not equally likely; in fact, some are arguably implausible. Thus, it is tempting to try to weigh the various points in Endeavour space by relative probability and significance. However, estimating the appropriate weighs is extremely difficult and perilous since historically there has been a tendency not count or under count the unexpected. The result would be to prepare for only the expected and thus potential agility would be constrained.

[78] For related discussion see Paul Bracken, Ian Bremer, and David Gordon (2008), Managing Strategic Surprise (New York: Oxford University Press), a compilation done for the intelligence community.

of the space. The formula for the benchmarked measure[79] is provided in Figure 3.9: Benchmarked Agility

$$\text{Benchmarked Agility} = \frac{S_{ES} - S_{Before}}{E_{ES} - S_{Before}}$$

Where

S_{ES} = volume in Endeavor Space where an Entity is able to be successful

E_{ES} = volume in Endeavor Space where an Entity is expected to be successful based on the "before" level of mission performance

S_{Before} = volume in the subset of Endeavor Space that corresponds to the "Before" where an Entity is able to be successful

Metric.

Figure 3.9: Benchmarked Agility Metric

3.10 AN ALTERNATE APPROACH

As previously stated, the development of a suitable Endeavour Space is problematic. There is, of course, no way to know if one's definition of Endeavour Space is appropriate. It will be a product of one's experiences and imagination. If the past is any guide, it is quite possible that the Endeavour Space will not include circumstances that should be considered and hence it will overestimate an Entity's Agility.

There is an approach that can be used to assess an Entity's Potential Agility without resort to the creation of an Endeavour Space. This approach is based upon the creation of a model of Agility, one that identifies the variables that affect an Entity's Agility and the relationships between and among these variables. This set of variables would include the enablers of Agility. SAS-085 has developed such a model for C2 Agility which will be introduced following a discussion of Agility as it applies to individual C2 Approaches, Entity C2, and C2 systems.

[79] Figure 3-4 is taken from The Agility Advantage (Figure V-57) as part of a discussion of the two Agility metrics Chapter 28.

Chapter 4 - C2 AGILITY

This part of the final report is devoted to providing readers with an understanding of how SAS-085 applies the concept of Agility to C2. This section concludes with a set of hypotheses that involve key C2 and C2 Agility related variables and the relationships between and among them. The testing of these hypotheses is one of the major tasks SAS-085 undertook in its effort to validate its conceptual model of C2 Agility.

4.1 C2

SAS-085 views C2, as previous NATO Research Groups have done, as a ***function***, one that allocates decision rights across the enterprise, the shaping of enterprise decision-making processes and the processes that acquire, manage, share, and exploit information in support of individual and collective decision making.

The term C2 has and continues to mean different things to different people. In addition to the manner in which SAS-085 employs the term here, the term C2 is used by some to be synonymous with a commander's authorities[80] and/or what commanders do as they exercise their authorities. Thus, every order given by a commander is considered by some to be C2. This way of looking at C2 anthropomorphizes the term and has led to an idiosyncratic view of C2. This has made it difficult for many to objectively assess C2 because such assessments are seen as being critical of individuals. For those readers who share this view, C2 Agility would equal the agility of a specific individual. A functional view of C2 leads to an analysis of C2 focused on a systemic exploration of approach options and their appropriateness for different missions and circumstances. This will, over time, greatly enhance our understanding of the options that are available, their strengths and weaknesses, and suggest new options and ways in which existing options can be improved.

4.2 C2 QUALITY AND VALUE

C2 is not an end unto itself; rather it is one of the essential means needed to be able to accomplish a mission or task. C2 is an enterprise function, whether the enterprise is a Collective or a traditional organization. C2 functions are accomplished by people, collections of people (organizations and Collectives), and the systems that support them. C2 involves four domains – physical, information, cognitive, and social. Accomplishing the functions associated with C2 serve to enable an enterprise to bring to bear, in a timely, effective, and efficient manner, all of the available information and assets necessary to be successful.

The value of C2 lies in its contribution to the success of the endeavours taken on by the enterprise. Measures of C2 Quality are based upon the degree to which the functions associated with C2 are accomplished, not whether the mission succeeded or not. C2 Agility is a reflection of how well these functions are accomplished over an Entity's Endeavour Space, that is over a range of missions and circumstances and as these missions and/or circumstances change. C2 Agility is a critical enabler of Entity Agility, which, in turn, is a reflection of the success of an Entity.

[80] Most military dictionaries define command and control as "the exercise of lawful authority and direction"

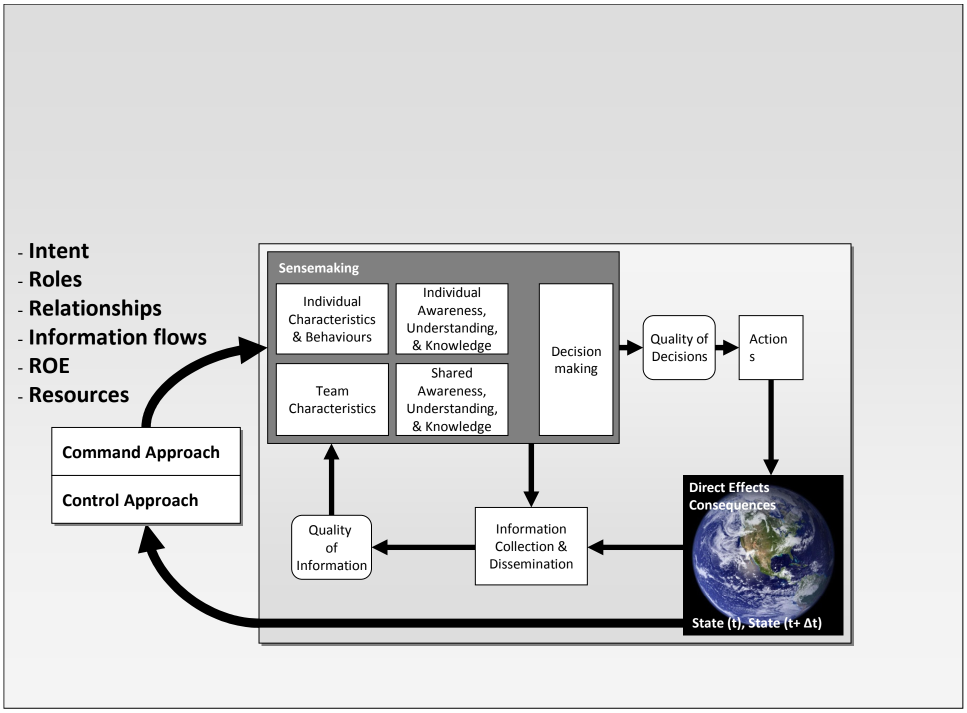


Figure 4.1: C2 Approach

Figure 4.1: C2 Approach, taken from the SAS-050 Final Report, depicts the two major aspects of C2. The first, sensemaking, has received the vast majority of attention over the years. Sensemaking encompasses three of the four elements of the well-known OODA loop, a functional model that has, to some, become synonymous with C2 (observe, orient, decide, act). "Act" is not part of C2; actions are an output of C2. Sensemaking begins on the edge of the information domain with the perception of available information and ends prior to taking actions.[81] The interface between sensemaking and action is the conveyance and expression of intent and/or orders. Sensemaking cycles take place synchronously and asynchronously through the Entity. One of the greatest C2 challenges is to ensure the coherence of these instances of sensemaking.

The second, often ignored aspect of C2, is the determination of how sensemaking will be approached. The lack of attention that this critical aspect of C2 has received may be due to the fact that, traditional C2 has been, in fact, the C2 Approach of choice for many militaries for so long. However, the choice of C2 Approach can profoundly impact the quality of sensemaking, and hence, C2 Quality. Sensemaking behaviours are, in fact, shaped by the selected approach to C2. Both aspects of C2 are dependent on Information Quality (includes not only observations of the environment but also information about the state of Self). In addition to the

[81] Alberts and Hayes, Understanding command and Control, Chapter 5 p.63

selection of a C2 Approach and operational sensemaking, C2 also includes the conveyance and expression of the decisions made to those who are to carry out these decisions. Thus, although a critical value chain metric, decision quality alone does not provide enough information to fully assess the Quality of C2 or its contribution to the mission. Many other variables shape and impact both the ability to adopt an approach to C2, given the mission and circumstances, and how well the sensemaking function of C2 is performed. The variables thought to have a significant impact on C2 Quality have been identified by SAS-050 in the NATO C2 Conceptual Reference Model.

Figure 4.2: C2 Conceptual Reference Model Variables, provides examples of variables thought to be significant in shaping and accomplishing sensemaking. Many of these variables not only affect C2 Quality but also C2 Agility.

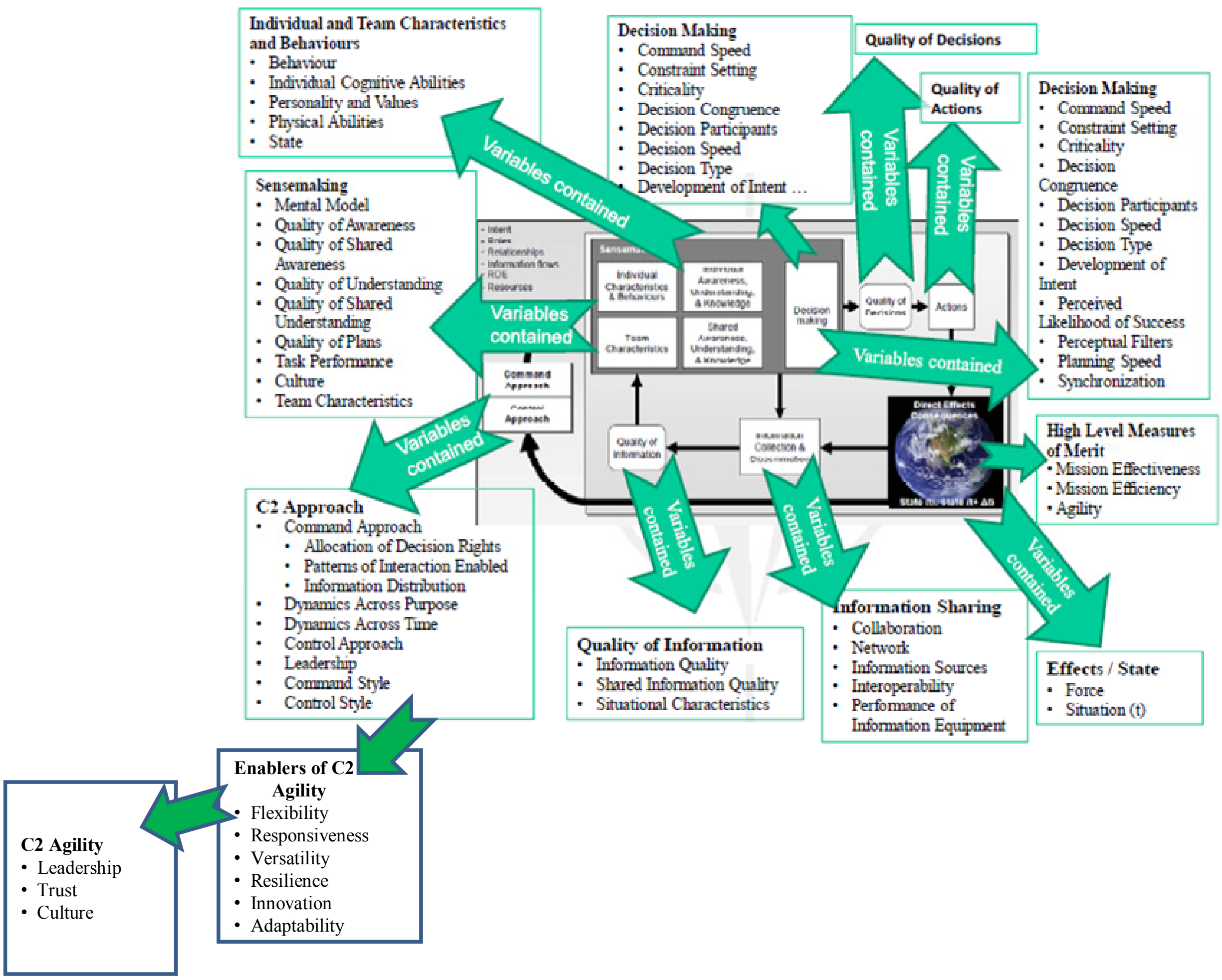


Figure 4.2: C2 Conceptual Reference Model Variables

4.3 APPROACHES TO C2

The first, and perhaps most important, task for anyone responsible for a function is to decide how the function should be accomplished. This specifies the specific tasks to be undertaken and creates the conditions that shape the behaviours that emerge as various tasks are being carried out in the context of an Endeavour.

C2 is no exception to this rule. If there was one approach to C2 that worked well for all missions and circumstances, then there would be no reason to revisit how C2 should be approached. If appropriate choices were always made and circumstances did not change then there would be no need to revisit the selection of an approach to C2 on a continuing basis. However, there is evidence that there is no 'one size fits all' approach to C2. There is also ample evidence that inappropriate choices are made as well as ample evidence that circumstances change in ways that affect the quality of C2.

Furthermore, how an Entity approaches C2 makes a significant operational difference. The adoption of an inappropriate or less appropriate approach to C2 has been associated with mission failure (see SAS-065 Case Studies, the CCRP Lessons Learned Publications, and the experiments reported upon in The Agility Advantage). An inappropriate approach may make it impossible, despite having extraordinarily capable individuals and highly advanced systems, to successfully accomplish C2 functions at the levels required by the mission in the circumstances that prevail.

In Chapter 2 - Orientation, the C2 Approach Space was introduced. Different regions in this space correspond to different C2 Approaches, some more networked-enabled than others. Figure 4.3: NATO NEC C2 Maturity Model Approaches, introduced earlier as Figure 2.5, depicts the C2 Approaches considered by SAS-065. The colored cubes represent regions in the space (along its diagonal) that are thought to be "coherent", that is, they are internally consistent where the distribution of information and the patterns of interaction support the way decision rights are allocated. This implies that off-diagonal approaches to C2, that could either be intentionally adopted or could be a result of the dynamics and characteristics of the situation, would be less effective and could even result in dysfunctional behaviours that lead to mission failure. For example, an approach where the DoI does not support the ADR can result in decisions being made without the information needed when that information was available.

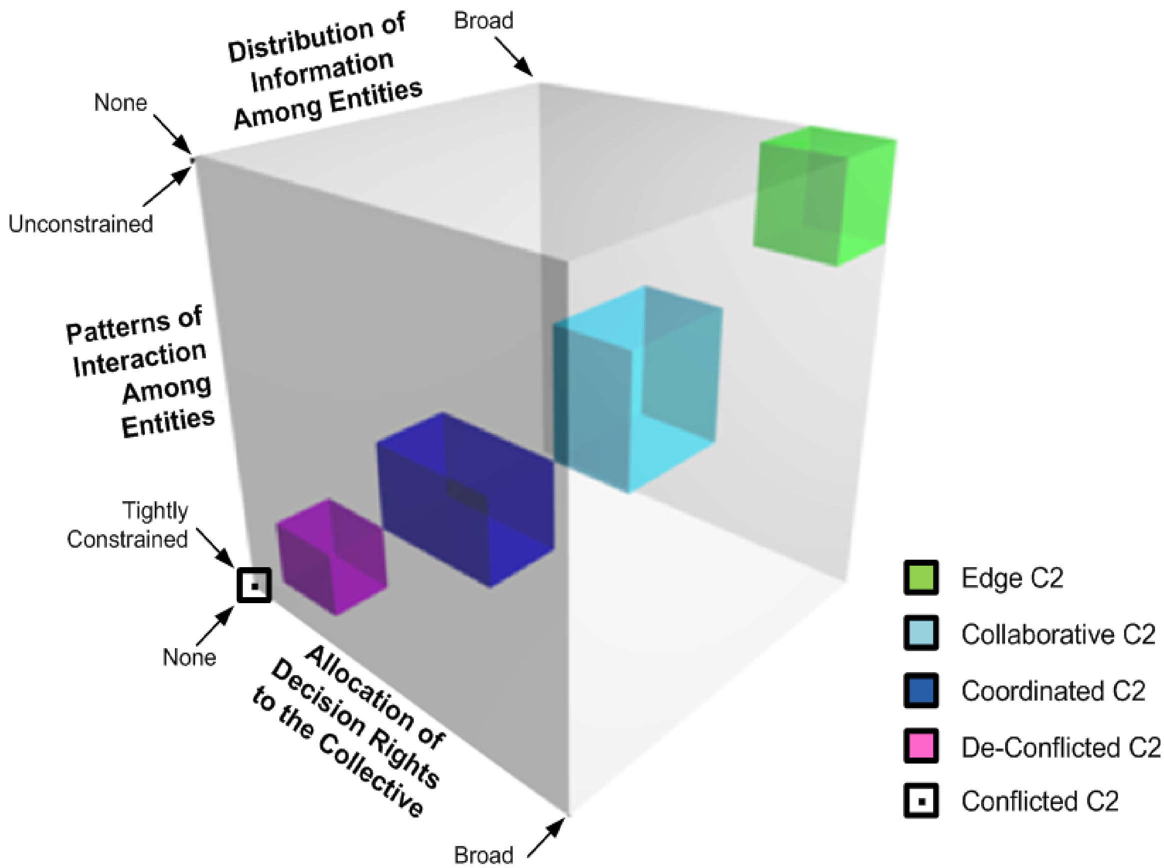


Figure 4.3: NATO NEC C2 Maturity Model Approaches

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However, having a coherent approach to C2 does not guarantee that it is appropriate for a given mission or set of circumstances. For example, some of these approaches require a far greater number of information-related transactions than other approaches. If the systems available cannot support these transactional loads or the resulting workload results in delaying access to critical information, this would make such an approach inappropriate for certain missions and circumstances.

A particular C2 Approach corresponds to a region within the C2 Approach Space. Those responsible for the C2 function not only can select from among a set of available C2 Approach options (e.g. the colored cubes depicted in Figure 4.3) but also can maneuver within each of these cubes to fine tune their approach. Furthermore, there will be cases, particularly in large enterprises and Collectives, where different approaches to C2 will make sense for different subsets of players and their interactions.

4.4 THE AGILITY OF A C2 APPROACH

An entity can improve C2 Agility by either improving the agility of one or more of the C2 Approaches it can adopt (C2 Approach Agility), by adding additional C2 Approaches to its toolkit, or by improving its ability to appropriately move among various C2 approaches (C2 Maneuver Agility – see next section).

In Chapter 3 - Basics of Agility, three ways of observing and expressing the Agility manifested by an Entity were presented. The first involved a graph of the value of a measure of success as a function of time that notes the range for the measure of success that is considered to be acceptable (see Figures 3.6 and 3.7). One line depicted on this graph represents the actual experience. A second line, beginning with the time the event took place, represents what would have happened had the event not taken place (baseline). Other lines could be added to this graph to represent other Entities or the same Entity with different capabilities, policies, and/or approaches to C2. The degree of Agility manifested is related to the differences between the lines depicted. This method is used to visualize the Agility manifested with respect to one change in circumstance.

The second way to visualize Agility involves the creation of an Agility Map. This method requires defining an Endeavour Space. As discussed previously, the Agility of a particular approach to C2 (e.g. de-conflicted, coordinated, collaborative, edge) is related to the size and location of the region(s) in Endeavour Space where an Entity, employing this particular approach to C2, can successfully operate. The values of two scalar measures of C2 Approach Agility (the proportion of Endeavour Space where an Entity can succeed and a benchmarked version of this), can be calculated from the same data used to create the Agility Map.

The C2 Approach Space defines a very large number of possible approaches to C2. These C2 Approach options vary considerably with respect to the degree to which they are network-enabled. The more network-enabled approaches being located progressively closer to the corner opposite from the origin. SAS-065 hypothesized that more network-enabled C2 Approaches will be more agile (be successful in a larger region of Endeavour Space). The rationale is that the more networked enabled a C2 Approach is, the more likely it is that it will possess characteristics and attributes associated with the enablers of Agility and thus, the more likely it will be for the Entity to be able to successfully accomplish C2 functions as circumstances change. SAS-085 tested this hypothesis and readers will find the results later in this report.

4.5 C2 MANEUVER AGILITY

C2 Maneuver Agility involves having an appropriate set of C2 Approaches in an Entity’s toolkit and the ability to appropriately employ them. Since the evidence suggests that there is no’ one size fits all’ C2 Approach, then it follows that more than one approach to C2 will, in all likelihood, be required to meet the needs of a diverse set of challenges. In addition, even if one’s current C2 Approach is appropriate for current circumstances, it may not be appropriate if these circumstances change. Thus, an Entity may need to change its approach to C2, in other words, to maneuver within the C2 Approach Space prior to or during an operation. Maneuver Agility involves the ability to:

- Recognize and understand that a change in circumstances has occurred and that the current approach to C2 is no longer appropriate.
- Understand which of the C2 Approach options it has is now appropriate, and,
- Transition to this new approach, in a timely manner.

Therefore, Entities need to develop and maintain a toolkit of C2 Approach options that is suitable for the Endeavour Space of interest.

SAS-065 in its presentation of the NATO NEC C2 Maturity Model discussed the appropriateness of various C2 Approaches (e.g. regions of the C2 Approach Space) as a function of the complexity and dynamics of the "mission space", which we refer to here as the Endeavor Space[82]. Figure 4.4: Endeavor Complexity and Appropriate C2 Approach shows a hypothetical mapping from the complexity or degree of challenge associated with the endeavour to the appropriate C2 Approach.

Endeavour Complexity	Appropriate C2 Approach
Low	De-conflicted
Medium	Coordinated
Medium-High	Collaborative
High- Very High	Edge

Figure 4.4: Endeavor Complexity and Appropriate C2 Approach

Although the inference that more network enabled C2 Approach are more appropriate for complex and dynamic challenges is unlikely to be true everywhere in Endeavor Space, it is consistent with the modern-day recognition, for example, that sometimes "it takes a network to defeat a network," as was concluded in the struggle with the Taliban in Afghanistan[83]. The hypothesized relationship between complexity, dynamics and network enabled C2 is one the hypotheses that SAS-085 tested.

[82] NATO NEC C2 Maturity Model p.86

[83] See, for example, Stanley McChrystal (2011), "It Takes a Network: the New Front of Modern Warfare," *Foreign Policy*, March/April. The concept of needing a network to defeat a network was introduced in a prescient book John Arquilla and David Ronfeldt (2001), Networks and Netwars: the Future of Terror, Crime, and Militancy (Santa Monica, Calif.: RAND).

4.6 C2 AGILITY

C2 Agility is an Entity's capability to successfully accomplish C2 functions over the entire Endeavour Space. An Entity's C2 Agility is related to the range of C2 Approach options an Entity can adopt, the Agility of each of these approaches, and its ability to maneuver in the C2 Approach Space. In other words,

> ***C2 Agility is a function of***
> ***C2 Approach Agility and C2 Maneuver Agility***

The greater the variety of C2 Approaches in an Entity's toolkit, the greater the Entity's potential C2 Agility. One measures C2 Agility in the same manner as C2 Approach Agility. However, while in the case of C2 Approach Agility only one C2 Approach is mapped onto Endeavour Space, in developing an Entity's C2 Agility Map all of the C2 Approaches in an Entity's toolkit are projected onto Endeavour Space to determine all of the regions where the Entity would be able to successfully accomplish its C2 functions. The assumption being that an Entity is able to dynamically adopt an appropriate C2 Approach. This assumption may not be realistic and should this be the case, an Agility Map that reflects the Entity's recognition-understanding-transition capabilities would need to be developed.

4.7 CONCEPTUAL MODEL OF C2 AGILITY

A conceptual model identifies the set of relevant variables related to the concept, in this case C2 Agility, and the relationships between and among these variables. The set of variables includes a measure of 'output', in this case, C2 Agility. A subset of variables forms a value chain. At this point in the development of a model of Agility, this value chain represents a set of hypotheses. Two other subsets of variables are of interest. The first is a set of variables, each of which can be "controlled". The second set of variables includes those that influence or mediate the effect that one variable has upon another.

Given the large number of variables identified by SAS-050, each of which has the potential to have an impact on C2 Quality and hence C2 Agility, there is no single graphic or diagram that can adequately capture the concept of C2 Agility. SAS-085 has therefore chosen to present a number of "views" of C2 Agility, each of which serves to illuminate one or more aspects of C2 Agility. These views are drawn from previous work as well as SAS-085 deliberations.

Figure 4.5: C2ACM Building Blocks is an overview depicting the three major building blocks of the C2ACM (Self, Environment, and Endeavour Space) and how these building blocks come into play in the selection of the most appropriate approach to C2. It highlights the importance of the interplay between Self and the Environment, which includes the Effects Space and its relationship to Endeavour Space. The Model of Self is composed of two models, a C2 Model and an Operations Model.

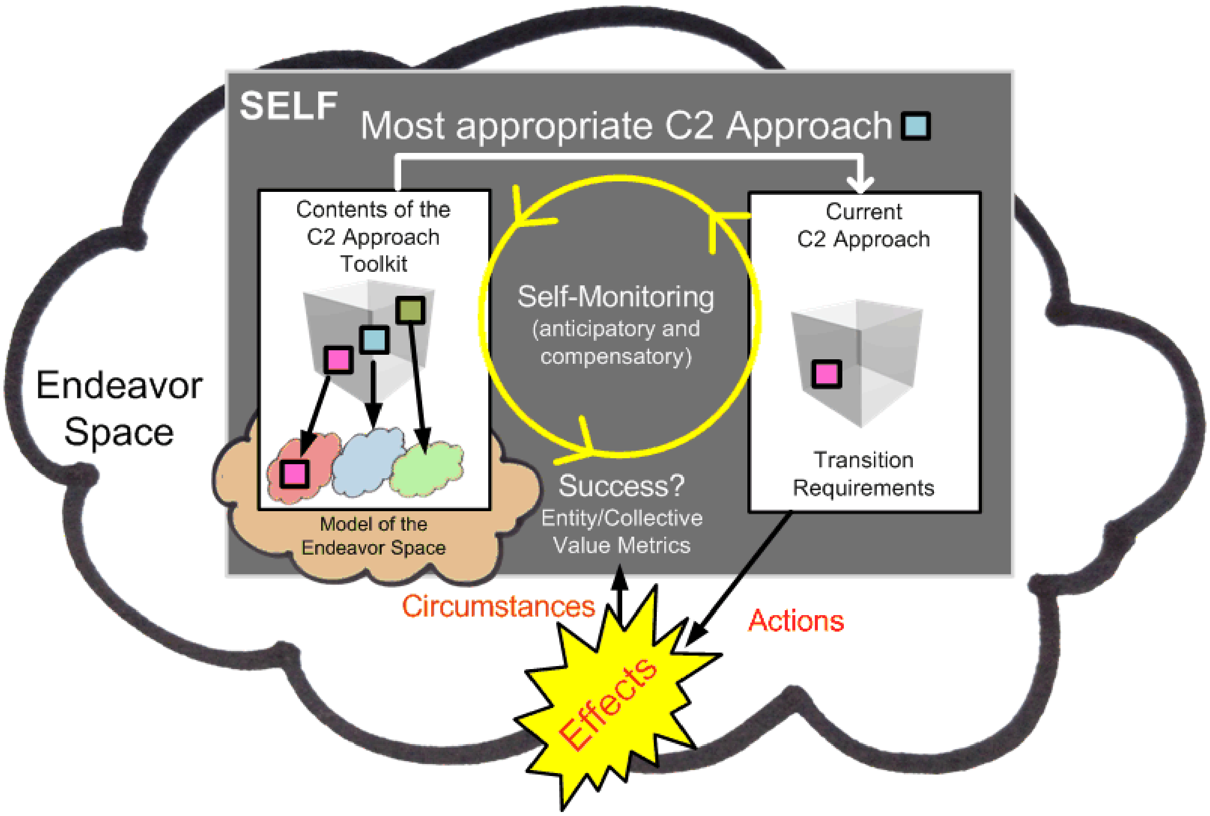


Figure 4.5: C2ACM Building Blocks

The C2 Model represents the process and value calculations that determine the C2 Approach that is selected and the intent that guides Operations. The C2 Approach sets the values of a C2-related set of variables in the Model of Operations that shapes its behaviours. The Model of Operations outputs a set of actions that are believed will have a desired impact on the Environment. The Model of the Environment determines what effect these, other actions (taken by parties other than Self), and other changes to environmental variables have on the values of variables in the Effects Space. The state of the environment is reflected by a point (region) in Endeavour Space. The C2 Model determines, based upon a Comparative Agility Map, the appropriate C2 Approach as a function of the circumstances and the State of Self.

C2 Agility is related to the ability of Self to keep its approach to C2 in line with changes in circumstances, the State of Self, and the appropriateness of the expression of intent to the C2 Approach selected. This ability of an Entity to recognize a change in circumstances and change the approach to C2 accordingly is depicted in Figure 4.6: A Change in the Appropriate C2 Approach.

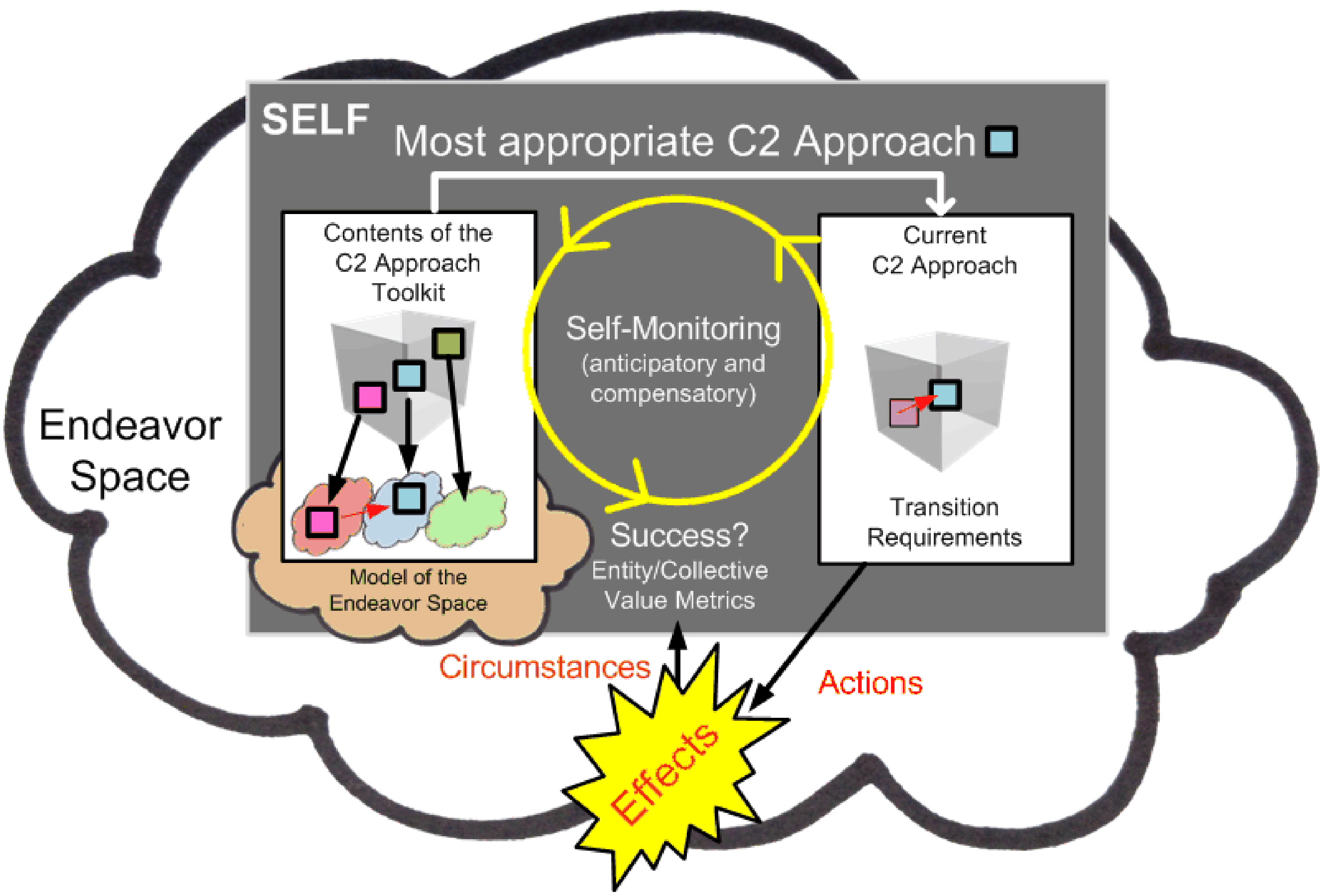


Figure 4.6: Change in the Appropriate C2 Approach

In reality one would expect a less than perfect matching of C2 Approach to a mission and set of circumstances as well as some transition delays to occur. Figure 4.7: Maintaining an Appropriate C2 Approach provides an illustrative example of the dynamics of maintaining an appropriate approach to C2.

The "cubes" in Figure 4.7 represent a set of coherent C2 Approaches, that is, approaches where the expression of intent, the DoI, and the PoI are consistent with the ADR. This Figure also depicts several changes in circumstances that result in a different C2 Approach being appropriate, where the appropriate C2 Approach is the one that is the most efficient approach that satisfies all mission requirements.

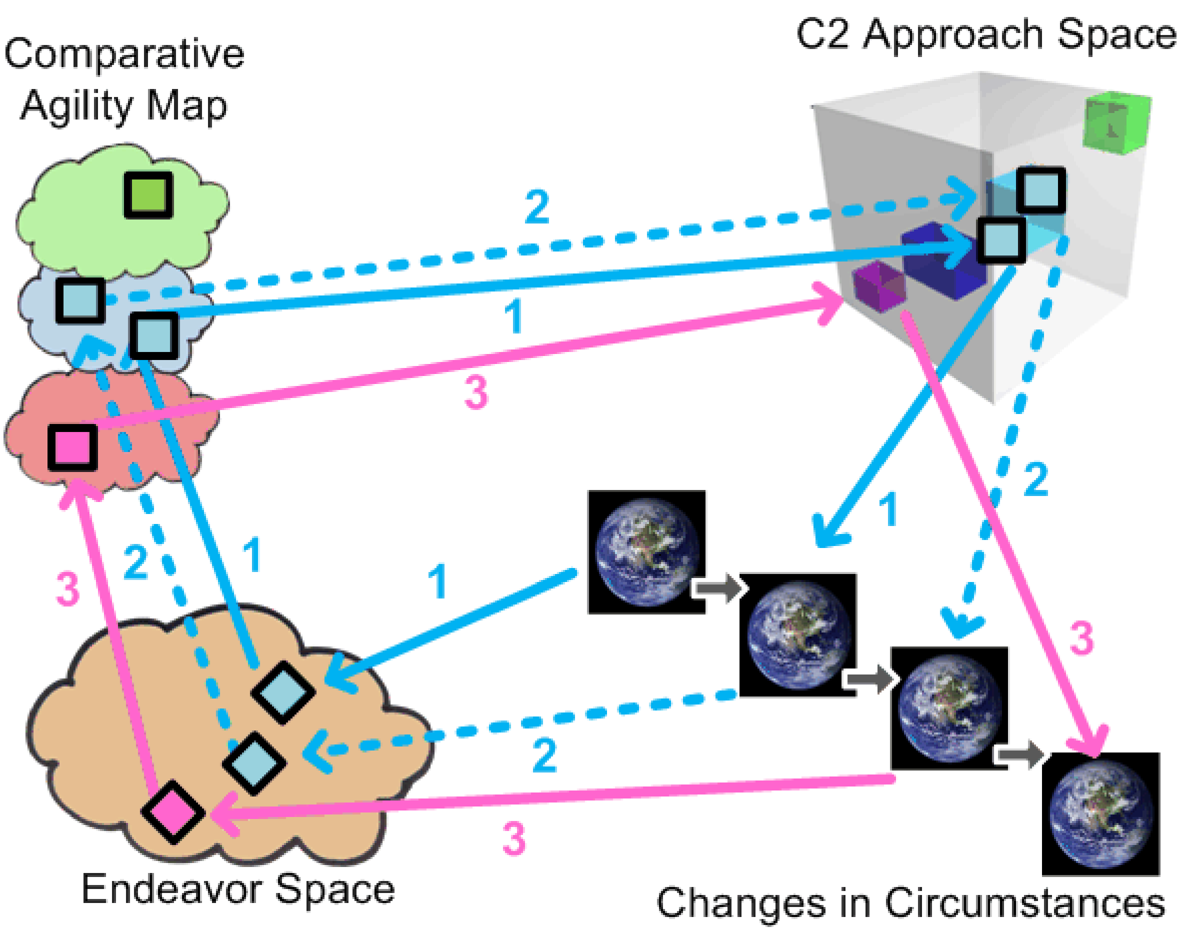


Figure 4.7: Maintaining an Appropriate C2 Approach

Initially, the appropriate C2 Approach is the same as the actual C2 Approach that results in acceptable performance. After the first change of circumstances, a more network-enabled approach (these approaches are color-coded to the NATO NEC C2 Maturity Model) is now required but the transition to the appropriate approach takes some time. This results in a time period where performance is not acceptable. A second change in circumstances occurs, again requiring a more networked-enabled approach, but this time the transition is immediate without any period of unacceptable performance. A third change in circumstances does not change the C2 Approach that is appropriate but impacts the ability of the Entity to maintain the appropriate C2 Approach. As a result, C2 performance becomes unacceptable. A fourth change of circumstances results in a less networked–enabled C2 Approach being appropriate. While the actual C2 Approach is not immediately changed, the Actual C2 Approach is now acceptable (meets mission requirements although is not the most efficient choice). Finally, the C2 Approach is adjusted and although still not the most efficient choice, C2 efficiency is improved.

Dynamically adapting one's C2 Approach to the mission and circumstances is undoubtedly challenging. Some have suggested that it may be more practical to adopt the most networked-enabled approach available and hence cover as many situations as possible. After all, are not the more networked-enabled approaches more agile? While it is true that more network-enabled approaches are more agile, they do not work well for certain missions and circumstances. Thus, adopting the most networked-enabled approach available will not guarantee success. Furthermore, there are tradeoffs involved between and among speed, correctness, shared awareness, costs, and risks.

4.8 HOMOGENEOUS V HETEROGENEOUS C2 APPROACH

Mandated by NATO-RTO-SAS, the initial concept of the N2C2M2 was designed by SAS-065 to assist NATO partners in the development of roadmaps for improving their C2 systems thus eventually reaching a *homogeneous* collective NATO C2 system for effective (joint and combined) "Coherent Network Centric" military operations (see Figure 2.4). That was arguably perceived to suggest Edge C2 as a "one size fits all" idealization.

The initial concept evolved substantially during the SAS-065 and SAS-085 studies as real world evidence revealed that 1) operations involving NATO often included creating Collectives involving non-NATO partners and 2) a homogeneous C2 approach was not feasible, or a useful ideal, for non-military aspects of operations such as those in stabilization and reconstruction, or even for military aspects involving non-NATO partners. Non-homogeneity has been strikingly evident in disaster-response operations in which military forces largely played supporting, albeit critical roles. Finally, based on evidence provided by SAS-065 case studies and the results of experiments it became clear, that Edge C2 is not always the best approach and that C2 maturity should be seen as allowing transition among the various C2 approaches (conflicted, de-conflicted, cooperative, and edge) so that the best or appropriate C2 approach for a given context can be adopted. The insights SAS-065 obtained from its case studies and experiments were reinforced by the validation studies performed by SAS-085.

As a result, SAS-065 came to view the cube model of C2 approach (Figure 2.5: NATO NEC C2 Maturity Model Approaches) in terms of how a set of disparate, yet more or less interdependent, entities – that is a collective of entities undertaking a complex endeavor (Alberts and Hayes, 2007) – can achieve focus and convergence by moving entities along the diagonal (from Conflicted at the lower left hand corner to Edge at the upper right hand corner of the cube) to converge on whatever C2 approach is appropriate in the situation at hand given the C2 maturity / C2 agility of the participants' C2 systems. The case studies demonstrated that heterogeneity of C2 approaches is the norm in complex endeavors and convergence would not necessarily occur over time.

The C2 approach of a collective in a complex endeavor will, almost by definition, be heterogeneous at the outset. However, whether the C2 approach should evolve to a homogeneous or heterogeneous approach will depend on circumstances such as the nature and dynamics of the endeavor, the C2 agility of the partners or entities, whether sufficient time is available for evolution, and whether or not the partners share common objectives and their level of mutual trust.[84] Because of limitations in trust and differences in capabilities, interactions and information sharing among entities as well as the allocation of decision rights may be deliberately limited.

It should be pointed out, however, that Collective C2 Maturity and C2 Agility are not easily measured when C2 is heterogeneous. In fact, an assessment of an appropriate single (homogeneous) Collective C2 Approach or a mix of approaches (heterogeneous) boils down to the difficult problem of maximizing the effectiveness of an endeavor, given the C2 Approaches Toolkits, the operational capabilities of the participating entities, and any other constraints that may exist.

Thus, for assessing the C2 Maturity and C2 Agility for heterogeneous C2, the C2ACM needs to consider context-dependent considerations that allow for activities such as building task clusters and in doing do match capabilities to needs and account for sharing of objectives and degrees of trust. To this end, it is necessary to specify the endeavors to a considerable degree, which necessitates use of scenarios in planning. For a more detailed discussion of such matters the reader is referred to Davis and Huber (2012) provided in Annex III of this report.

4.9 C2 AGILITY AND SELF-AWARENESS

As can be seen from Figure 4.7: Maintaining an Appropriate C2 Approach as Circumstances Change, situation awareness (understanding what C2 approach is appropriate) and Self-monitoring (actual C2-related behaviors) are both necessary prerequisites for C2 Agility. Entities need to understand their current state and how it impacts their ability to implement each of the C2 Approaches in their toolkit. This includes, at a minimum, the state of their communications and information systems, the levels of trust that exist across the enterprise, their experience with the different C2 Approach options, and their level of understanding of the mission and situation. All of these factors need to be considered in making a choice among C2 Approaches.

In addition, the ability of the Entity to maneuver within the C2 Approach Space, that is, to transition from one approach to another needs to be considered in selecting a C2 Approach. If, for example, to move from a coordinated to a collaborative approach, requires a considerable amount of time and effort, this may make it advisable to initially adopt a collaborative approach even if a coordinated approach would be adequate so as to ensure against a change in the environment that would later require a more networked-enabled approach. This is an example of the fact that the need to maneuver depends, in part, on where an Entity is positioned in the C2 Approach Space. This, in turn, depends upon relative C2 Approach Agility.

[84] and the Huber and Moffat (2011) have proposed using the N2C2M2 as a conceptual framework for the evolution of convergent defense planning in Europe, as called for by Force transformation in NATO and more recently by the more modest concept of "Smart Defense." Interestingly, this evolution will itself be a highly complex endeavor involving all European governments and numerous military and industrial stakeholders in Europe United States with diverging interests and objectives. In contrast to complex endeavors in the areas of combat operations, peacekeeping and stabilization as well as response to large-scale man-made and natural disasters, time is a controllable factor, at least in principle. This is confirmed by the SAS-085 validation case study on the development and testing of an agile C2 system for the security of the Vancouver Olympics (Farrell, 2010).

While organizations have invested a great deal of resources and effort to develop situational awareness, this does not always extend to C2-related Self-awareness. If one is used to considering one's C2 Approach as a given, than it is unlikely that one would have developed the capability to monitor and understand the aspects of the environment and Self that impact the appropriateness of a C2 Approach.

4.10 MANIFEST AND POTENTIAL C2 AGILITY

Measuring the Agility manifested by a particular Entity involves directly observing the outcomes associated with a specific Entity undertaking a specific mission in a particular circumstance. For each instance observed, one can make a determination of success or a lack thereof. Each of these would map to a single point in an Agility Map. Direct observation is limited to what actually takes place. Thus, even over time, a relatively small number of points will be obtained and they will be located in regions of Endeavor Space that are unlikely to be representative of the entire space. To fill in enough points and to ensure that these points are distributed throughout the Endeavor Space therefore requires being able to simulate the behaviors involved. An Agility Map, appropriately populated by a combination of points from real world observations and simulated outcomes, can serve as an estimate of an Entity's Potential Agility, but there are, as indicated previously, reasons why this approach is problematic.

The problem with using an Agility Map as the sole means of estimating Entity Agility stems from the need to construct an appropriate Endeavor Space and the difficulties in simulating all of the behaviors involved. While constructing an Endeavor Space does not require point predictions, it does require imagining what is possible, if not likely to occur. Black Swans are unlikely to be included in many Entity Endeavor Spaces and history shows us that these 'extremely unlikely' events occur more frequently that people think and they can be catastrophic. The lesson SAS-085 takes away is that one needs to be able to deal with unexpected and unfamiliar circumstances. In other words, Entities need to prepare without knowing the specific nature of the events to prepare for. Therefore, it is prudent to develop an alternative approach to measuring an Entity's Agility, one that does not rely solely on identifying a set of specific missions and circumstances and simulating the behaviors of interest.

An alternative approach is to construct a model of Potential Agility based upon the relationships between and among the enablers of Agility and the variables that influence the values of these enablers. That is, to model both the inter-relationships between and among the enablers (e.g. flexibility and responsiveness) and the characteristics of entities that influence the degree to which an Entity possesses each of the enablers (e.g. education, training and flexibility). The output of such a model would be an estimate of an Entity's Potential Agility that was independent of the mission or circumstance. It would instead be a reflection of the characteristics and capabilities of the entity. An entity could seek to improve Potential Agility by changing its characteristics and by investing in new or improved capabilities.

Figure 4.8: Manifest and Potential C2 Agility depicts both ways of estimating Agility and a method to cross-validate the results. The Model of Manifest Agility contains representations of the state of Self, the state of the External Environment, the Endeavor Space, the C2 Approaches that can be adopted, and the variables of interest (those that determine whether or not an entity is successful).

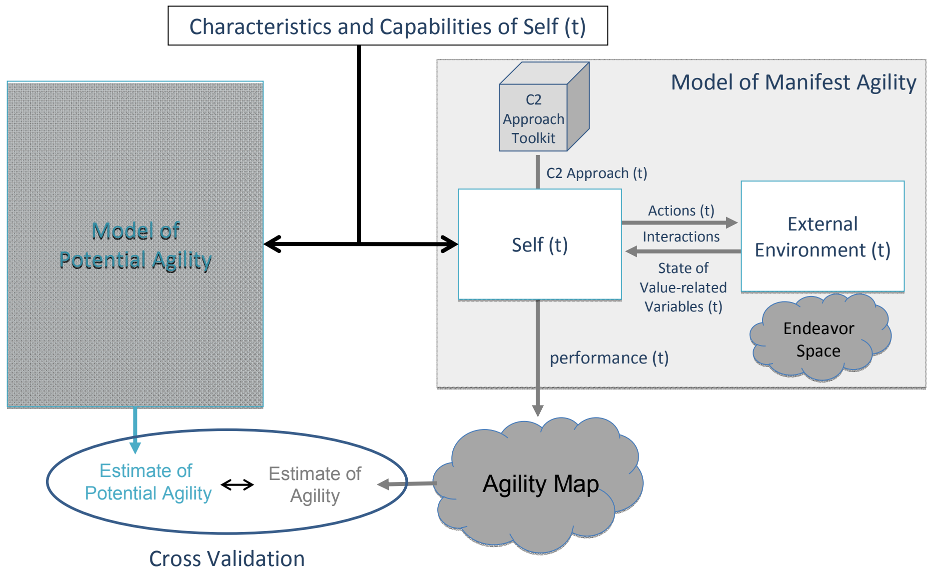


Figure 4.8: Manifest and Potential C2 Agility

The behaviors that are simulated include the selection of a C2 Approach, C2 functions and processes, the mission-related actions an entity can take, and the interactions between an entity and the environment. The Model of Manifest Agility is used to determine the performance of the entity that is reflected in the Agility Map as a function of different approaches to C2 and different mission and circumstances. The Entity Agility is estimated using this Agility Map. Also depicted is the Model of Potential Agility. The output of this model is an estimate of Potential Agility that is based upon the characteristics and capabilities of the Entity. These two estimates provide an opportunity to cross validate these two different ways to estimate Entity Agility. SAS-085 focused on Manifest Agility. The case studies reported on instances of Agility or a lack thereof; while the experiments developed Agility Maps for simulated entities. The results of these analyses could be used to provide inputs to the development of a Model of Potential Agility.

4.11 C2 AGILITY RELATIONSHIPS

As previously stated, C2 Agility is a function of both the Agility of the C2 Approaches that are available (C2 Approach Agility) and C2 Maneuver Agility. In addition, C2 Agility also is a function of the Agility of C2 systems, the Agility of C2 policies and processes, and, of course, the Agility of the individuals involved. The Agility of one of these can compensate for a lack of performance or Agility in another. As C2 Agility-related experiments have shown, C2 systems Agility, in the form of resilience, can have a significant impact on the effectiveness and efficiency of a C2 Approach. Similarly, flexible policies and practices can enhance the Agility of a C2 Approach.[85] In a contested environment, one must assume that C2 systems performance would suffer some amount of degradation. Thus, awareness of the state of supporting C2 systems is required in order to assess the appropriateness of a given approach to C2. The ability of a C2 system to cope with various stresses (a function of C2 Systems Agility) is thus related to both C2 Approach Agility and C2 Agility (see Figure 4.9: From C2 systems Agility to C2 Agility).

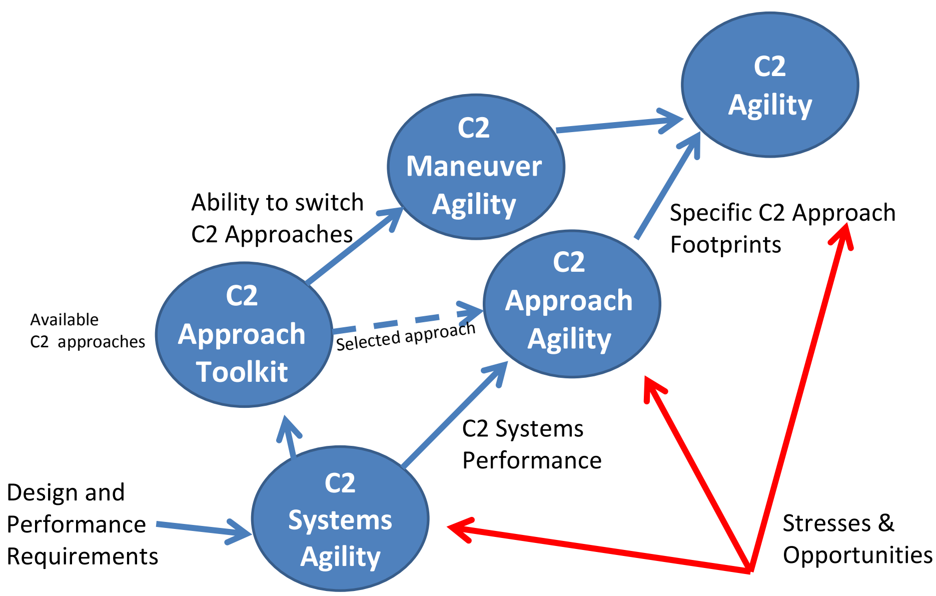


Figure 4.9: From C2 Systems Agility to C2 Agility

85 For example see The Agility Advantage Figure V-5. The results of experiments that compared the Agility of organizations that could dynamically adapt their information sharing policies with those that only had one policy option showed that a flexible policy resulted in significantly more Agility. Also see Alberts and Manso 17th ICCRTS Paper 086

4.12 C2 AGILITY HYPOTHESES

With the development of the material presented thus far, SAS-085 was able to articulate the concept of C2 Agility by incorporating and extending the theory of networked enabled capability (NEC), the NATO C2 Conceptual Reference Model (SAS-050) and the NATO NEC C2 Maturity Model (SAS-065). Thus, the model of C2 Agility represents a synthesis and extension of existing C2 research. However, we recognize that the resulting C2ACM, rather than being a collection of "truths", is actually a set of testable hypotheses and implications. Efforts to test these can, if the results are supportive, increase confidence in the model's correctness; if not supportive, they can identify weaknesses that require modifications to the model.

A hypothesis should be a clear, testable statement articulating a plausible explanation for observable behaviour. Testing an hypothesis involves constructing a null hypothesis in such a way as to allow gathering of data that can be used to determine if the null hypothesis can be rejected. Rejecting a null hypothesis does not equate to the proving any alternate hypothesis [86]. The null hypothesis is sometimes called the "no difference" hypothesis (e.g.; there is no difference in the level of agility for the C2 Approaches identified in the NATO NEC C2 Maturity Model, there is no difference if a specified enabler of agility is present or not). SAS-085 has adopted a less formal convention in discussing C2 Agility related hypotheses in that only the alternative hypotheses are presented. The null hypotheses are implicit.

While the case studies took a subjective qualitative approach when considering the C2 Agility hypotheses, the Campaign of Experimentation took an objective quantitative approach and employed appropriate statistical tests.

Our articulation of a C2ACM involves variables and relationships that we believe are of first-order significance. Without knowledge of the values of these variables and of the form of the relationships between and among them, one would not be able to explain the Agility that was or was not manifested by a given approach to C2 in a particular circumstance, or the relative C2 Agility of an Entity capable of maneuvering within the C2 Approach Space (employing a set of C2 Approaches as appropriate), given an Endeavour Space.

The C2ACM includes a previously identified set of enablers of Agility[87], each of which is believed to have a unique contribution to make to C2 Approach Agility and to C2 Maneuver Agility, either indirectly (increased C2 Agility because the Agility of one or more C2 Approaches improves) or directly by contributing to the range of approach options available, the ability to select an appropriate approach options, and/or the ability to transition from one approach to another. These beliefs are, in fact, also hypotheses that need to be tested.

An "Agility Value Chain" lies at the heart of SAS-085's articulation of C2 Agility. The following set of C2 Agility-related hypotheses, organized around this value chain, was investigated as part of this validation effort.

[86] A null hypothesis traditionally asserts that there is no difference between two groups or that no relationship exists between or among a set of variables. A model to be tested, in this case a model of C2 Agility, consists of relationships. Thus, if it can be shown that a relationship exists, the null hypothesis will be rejected under the conditions associated with the test. Thus, theories can never be definitively proven, rather they are supported by the evidence to date.

[87] See Power to the Edge – Chapter 8 provided a list of "attributes" or "key dimensions" of Agility- what SAS-085 refers to as enablers

C2 Agility is fundamentally about the effectiveness, efficiency and risks associated with adopting one or more approaches to C2 for different missions and in different circumstances. Therefore, the first thing we need to test is that the C2 Approaches defined by the NATO C2 Maturity Model are reasonably distinct and that these differences can be recognized. The first hypothesis then is:

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

This hypothesis amount to saying that there are actual differences between and among the approaches, not just differences in name. As discussed previous, we are stating an "alternative" hypothesis, where the implicit null hypothesis is "There are no (significant) differences between C2 Approaches."

The next two hypotheses stems from turning the cliché "there is no one-size fits all' approach to C2" and the belief that network enabled capabilities are good into testable propositions.

- H2: No one approach to C2 is always the most appropriate
- H3: More network-enabled approaches to C2 are more appropriate for more challenging situations (Complex Endeavors); while less network-enabled approaches to C2 are more appropriate for less challenging missions/circumstances

Readers should note that although H3 could be read to mean that more network enabled approaches are always the best for more challenging situations, it should be understood to say that they are typically more appropriate.

Agility is not about being best for one mission/circumstance, but about being successful over a range of missions and circumstances. The following hypothesis addresses the Agility of network-enabled C2 Approaches.

- H4: More network-enabled approaches to C2 are more agile (possess more C2 Approach Agility)

Each dimension of the C2 Approach Space represents a characteristic that could affect Agility. The next hypothesis looks at this.

- H5: The dimensions of the C2 Approach Space are positively correlated with Agility.

If H5 is supported by the evidence, then the location of a C2 approach in the C2 approach space matters. The next two hypotheses are related to specific locations or regions in the C2 Approach Space.

- H6: More network-enabled approaches to C2 are better able to maintain their intended positions in the C2 Approach Space.
- H7: On-diagonal (balanced) approaches to C2 are more agile than off-diagonal approaches.

Adopting more than one approach to C2 enables an Entity to position itself within a larger region of the C2

Approach Space, that is, an entity has more C2 approach options. Having more C2 from which to choose, not only enables an Entity to initially position itself in an advantageous location within the C2 Approach Space, but as circumstances change, the Entity has a larger set of C2 Approach options from among which to choose to reposition itself. This translates into being able to successfully operate in a larger region of the Endeavour Space and thus be more agile.

The NATO C2 Maturity Model defines five levels of increasing C2 Maturity that correspond to the ability to locate in successively larger regions of the C2 Approach Space. The NATO model assumes that Entities have perfect C2 Maneuver Agility. However, in reality an Entity may not be able to (or may not need to) adopt all of the C2 Approaches included in a given maturity level or may not be able to or need to transition between and among them seamlessly. H4, if it is supported by the evidence, may imply that one simply needs to adopt the most network-enabled approach and thus maneuver is not necessary. However, H2 would imply that maneuver is necessary. The question is “What is gained by having additional C2 Approach options as one’s C2 Maturity increases?”

Maneuver implies that one knows not only where one would like to be located but also where one is currently located. Thus, the ability to maintain an understanding of where one is located in the C2 Approach Space is a necessary but not sufficient condition for successful maneuver. The following hypotheses test the assertion that the ability to maneuver in the C2 Approach Space matters.

- H8: Increasing C2 Maneuver Agility increases Agility
- H9: More mature C2 capability is more agile than the most agile C2 Approach that can be adopted
- H10: Self-monitoring is required for C2 Maneuver Agility

The C2ACM identifies a set of enablers of Agility (including responsiveness, versatility, adaptability, flexibility, resilience, and innovativeness) that individually and collectively affect the degree of Agility that is or could be manifested. Furthermore, there are synergies between and among these enablers that generate non-linear gains in Agility. The following hypotheses address the completeness of the set of enablers that have been identified and their individual ability to affect 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

Figure 4.10: Testing of Hypotheses lists the hypotheses that SAS-085 considered and indicates, by a check mark, whether they were tested in the cases studies or the experiments or both. A check mark does not imply that evidence was found to support a hypothesis.

Hypothesis	Case Studies	Experiments
H1: Each of the NATO C2 Maturity Model C2 Approaches is located in a distinct region of the C2 Approach Space	√	√
H2: No one approach to C2 is always the most appropriate	√	√
H3: More network-enabled approaches to C2 are more appropriate for more challenging situations (Complex Endeavors); while less network-enabled approaches to C2 are more appropriate for less challenging missions/circumstances	√	√
H4: More network-enabled approaches to C2 are more agile (possess more C2 Approach Agility)	√	√
H5: The dimensions of the C2 Approach Space are positively correlated with Agility		√
H6: More network-enabled approaches to C2 are better able to maintain their intended positions in the C2 Approach Space		√
H7: On-diagonal (balanced) approaches to C2 are more agile than off-diagonal approaches	√	√
H8: Increasing C2 Manoeuver Agility increases Agility	√	√
H9: More mature C2 capability is more agile than the most agile C2 Approach that can be adopted		√
H10: Self-monitoring is required for C2 Manoeuver 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	√	

Figure 4.10: Testing of Hypotheses

Chapter 5 - VALIDATION APPROACH

5.1 VALIDATION OBJECTIVES

The primary goal of SAS-085 is to develop a better understanding of C2 Agility and support NATO and member nations in their efforts to improve their C2 Agility and to meet the mission challenges they face. To accomplish this goal, SAS-085 realized that simply developing and articulating a conceptual model was not sufficient to realize this goal. While a C2ACM would serve to explain to others what we mean by C2 Agility and guide efforts to identify and understand the relationships between characteristics of Entities, their potential C2 Agility and mission success, without vigorous efforts to validate this model and test the hypotheses associated with this model, our task would remain unfinished. Thus, validation is a key step in the journey to develop a reliable C2ACM and a set of findings in which practitioners, researchers, educators, and students may be confident. The members of SAS-085 took this obligation seriously. Therefore, the majority of SAS-085's time and efforts were devoted to a validation effort, the objective of which was to ensure that the C2ACM and the conclusions that this model points to are *clear, applicable and valid*[88].

- Clarity: Given the challenging nature of the subject of C2 Agility and the number and variety of NATO members, the SAS-085 Research Task Group sought to ensure that the C2ACM was clear and easy to understand.
- Applicability: While the first step in introducing a new idea is to make sure that people understand the concepts. SAS-085 believes that C2 Agility is more than of academic interest. Thus, we wanted to make sure that the model we developed and the Agility-related metrics[89] and measures it contains can be applied to real world militaries and is applicable to the situations faced by them.
- Validity: The C2ACM embodies a set of testable hypotheses that involve relationships between and among the characteristics of Entities, the Agility they manifest, and mission success. The validity of the model is related to the extent to which these hypotheses are supported by empirical evidence and analysis. Thus, our validation findings are limited to the scope of these hypotheses.

The simulation based experiments and retrospective case studies conducted by SAS-085, have made members confident that improved C2 Agility is a critical capability. Therefore, we believe that improving Agility should be a priority and receive immediate attention. We realize that for organizations to invest their resources and change their priorities, they need to be shown that the C2ACM and associated findings have been validated.

5.2 VALIDATION METHODOLOGY

Validity[90], which means ensuring that a model or tool is appropriate for the uses or purposes for which it is designed or intended (DoD Directive 5000.59 "DOD Modelling and Simulation (*M&S*) Management," USD (*AT&L* August 8, 2007) is assessed through the following three lenses.

88 This discussion of validation draws heavily upon Chapter 7 of the NATO NEC C2 Maturity Model.

89 SAS-085's uses the word metrics to include what some refer to as "indicants." Indicants are employed when direct measurement of the concept or variable of interest is impractical.

90 The terms Validation and Verification (V&V) are often used together particularly with respect to a product or system. In this context validation is the process to determine if the product or system is appropriate (right product), that is, does it meet the

- Expert Validity (sometimes called Face Validity)—does the model and its behaviours appear credible to those who are knowledgeable in the field?
- Construct Validity—does the model include all the relevant factors? Are all the relevant relationships included?
- Empirical Validity—does the model produce patterns or relationships that are observed in the *real world*? Alternatively, does the model behave in a way that is consistent with observed behaviours? That is, are the hypotheses that are incorporated within the model supported by empirical evidence?

SAS-085 assessed Expert Validity through a peer review process, and assessed Construct and Empirical Validity by analyzing the results obtained from a series of experiments and a set of case studies, both of which contributed in a different way to the overall validation effort. Case studies explore real-life endeavours that NATO and their member nations have been involved in, while experimentation provides controlled settings needed to systematically explore and understand key relationships between C2 Approach characteristics and attributes of the endeavour. Done with appropriate rigor, the results and findings of simulation based experiments and retrospective case studies provide different perspectives that can increase confidence in the model.

A case study is a detailed analysis of historical situations where evidence is sought that may prove or disprove various pre-conceived notions or hypotheses related to the concepts being explored. The advantage of case studies is that any conclusions drawn from the analysis pertain to real situations, thus case studies provide 'empirical' validity. Further, case studies provide a richness of information that guides analysts in their interpretation of the observed data and how they should be compared to the C2ACM. Case studies can also identify additional causal variables and pathways, advancing the state of theory and suggesting new and revised hypotheses. In contrast, comparisons based upon overly aggregated data (i.e. such as casualties in a campaign as a function of per-capita GDP of the countries involved and force sizes) suffer from the effects of hidden variables and other problems[91]. The disadvantage of case studies is that any conclusions drawn from the analysis may pertain to only to those situation(s) being analyzed. It may be difficult to generalize and extrapolate to other situations. The cases (see Chapter 7 - Case Study Findings) looked at what C2 Approach(es) were adopted, whether or not the adopted C2 Approach(es) were appropriate for the mission and circumstances, and if not, was the Entity able to recognize this mismatch and change their C2 Approach. Also of interest in the case studies were the consequences of manifested (observed) Agility, or a lack thereof.

needs of the 'customer'. Verification addresses the question "are we building it right?" as in a system – see Bohem 1981. In modeling and simulation, "verification" is done to assure that a program (software) correctly implements the design, whereas "validation" addresses the question of whether the design itself is sufficiently "correct" for the intended purposes. These are part of a quality management process. With respect to a conceptual model, the issue is whether or not the model correctly (adequate for the purpose(s) at hand) represents the phenomena (behaviors) of interest. Such a model (theory) is valid to the extent that it accomplished this.

[91] The importance of case studies and the shortcomings of over-aggregated empirical analysis are discussed in a recent review, *Dilemmas of Intervention: Social Science for Stabilization and Reconstruction*, edited by Paul K. Davis, Santa Monica, California: RAND:2011, pp.326 ff.

Since controlled "real" experiments are out of the question in most cases (i.e. we cannot arrange for an orderly set of wars and crises under controlled conditions form which to collect the empirical data desired), analytic experiments are attractive mechanisms, despite their limitations.[92]

An experiment involves the ability to control one or more variables and observe results in the context of a simplified construction of the world. The methodology adopted for SAS-085's experimentation combined the focus and organization of a Campaign of Experimentation (explained in the next section) with the analytical power of meta-analysis to allow comparability of results across experimentation platforms. The SAS-085 C2ACM and its related background theory were used as the basis for the design of the experiments, which produced rich and varied data in support of a robust (cross-experiment) analysis and validation.

The SAS-085 experiments were all agent-based model simulations that could carry out a mission or task using one of a set of C2 Approaches. Although originally designed for a variety of purposes, the simulation models, employed by SAS-085 were after some adaptation, were used to generate a rich set of data that focused on a common set of hypotheses, as part of and in the context of a Campaign of Experimentation. The comparability of the data was enhanced by employing meta-analysis.

Thus, SAS-085 analytic experimentation allowed us to 1) control or influence the values of key variables of interest (e.g. the C2 Approach) 2) explore a range of missions and circumstances, and 3) collect a great deal of detailed information about behaviour and consequences. An advantage of employing multiple simulation models and experimental venues is that it facilitates the exploration of a large and diverse Endeavour Space and provides a better estimate of the potential Agility of various C2 Approaches. Furthermore, it strengthens the tests of statistical significance and makes it possible to generalize the findings beyond that which would be appropriate if only one model were employed. A disadvantage of such simulation however, is that a good deal of real world richness is absent. Such richness is better captured in case studies. The series of experiments, conducted by SAS-085, looked at hundreds of mission-circumstance pairings and collected detailed information about behaviours and results. Each run was mapped to a position in the C2 Approach Space, thus providing an opportunity in the meta-analysis to look at hypotheses that the case studies could not. In addition, the experimental results were used to calculate the potential Agility of each of the C2 Approaches and, assuming perfect C2 maneuver Agility, the Agility of different levels of C2 Maturity.

SAS-085 followed an inductive, iterative process for building and testing its C2ACM, and in its articulation of C2 Agility Theory[93]. The first step in this process was the identification of potentially useful experimental venues or simulations[94] and case studies. This often originated with a specific member of SAS-085, though some were nominated by the group of members from a particular nation. In addition, for the case studies, attention was paid to getting a rich variety of cases that included missions NATO or NATO nations must be prepared to carry

[92] To be sure, it is sometimes possible to find or arrange for "natural experiments" that offer a degree of control, as – in our context – if different C2 Approaches are used in different but similar provinces of a country during a real world complex endeavor. SAS-085 did not have such natural or quasi-experimental data to work with as such opportunities are rare. Statistical techniques can also be employed to create a condition of "control" in some cases.

[93] George, A. and Bennett, A, Case Studies And Theory Development In The Social Sciences, MIT Press, 2005 and Eisenhardt, K. M. "Building Theories from Case Study Research." *The Academy of Management Review 14(4):* 532-550*,* 1989; Yin, R. *Case Study Research: Design and Methods*, 3rd Edition, Sage Publications Inc., 2002.

[94] SAS-085 experiments included those that employed an instrument venue (e.g. ELICIT) or a simulation model (e.g. WISE). These will be described in detail in the section on Experiments.

out in the foreseeable future. Cases or simulation models that dealt with Complex Endeavours were given priority for further exploration. Proposed case studies were initially assigned to one or more members to confirm the availability of sufficient relevant information to contribute to our validation effort. Simulation models or venues were checked to see if they were able to instantiate and instrument a variety of C2 Approaches. The results of this initial feasibility study were then reported back to the group as a whole, and where adequate information (case studies) and adequate capability (experiments) were available, a sub-group was formed to pursue each case or experiment.

Work on these often required more than a year of effort. The bulk of the effort was conducted between formal meetings, with heavy reliance on interactions over the internet. During the period when these efforts were underway the formal meetings, which occurred as often as four times per year, were largely devoted to focused discussions about conclusions, reporting the applications to the larger group for constructive criticism, organising new applications, and exploring the implications for C2ACM and efforts to improve Agility.

Once a case study was selected and the initial material identified, the work process within the teams completing the cases utilized a template that guided the data collection. Once it was decided to use a particular experimental venue or simulation model, the variables that were controllable were identified and instantiated in accordance with an overall experimental design that was developed with the hypotheses in mind.

SAS-085 members performed two meta-analyses – one that looked across the results of findings from the individual case studies, and the other that integrated the data provided by the series of experiments. Details of these analyses are discussed in the Chapter 6 - Campaign of Experimentation and Chapter 7 - Case Study Findings.

However, neither the analyses of experimental data nor the case studies were ends in themselves. They were designed and employed in an effort to:

- Discover and correct potential sources of ambiguity and confusion in our articulation of C2 Agility and related concepts.
- Ensure that the hypotheses derived from the C2ACM are supported by empirical evidence.
- Identify the variables needed to describe C2 Approaches and assess C2 Approach and Maneuver Agility, and the factors that impact C2 Agility.

Hence, SAS-085 carried on a running dialogue, both in the context of specific applications and on a cross-cutting basis, on how the logic and presentation of the C2ACM might be improved.

5.3 A CAMPAIGN OF EXPERIMENTATION

SAS-085 recognizes that improving our understanding of C2 Agility and translating this understanding into improvement in the practice of C2 will require far more than the limited number of cases studies and experiments that could be accomplished, given the resources and time available. What is needed to ‘operationalize’ C2 Agility is a Campaign of Experimentation (Alberts & Hayes, 2005), one that is international in scope and incorporates a diverse set of venues, models, and experiments. The concept of a Campaign of Experimentation was developed to support military experimentation efforts designed to explore the tenets of

Network Centric Warfare (NCW, now NEC), by extending the Code of Best Practice for Experimentation (2002). The development of this 'best practice' was undertaken in recognition that the information age transformation of military organizations presents a host of issues that needed to addressed in a systematic way. This, in turn, required that a rich body of empirical evidence be assembled. Such a body of evidence requires the design and conduct of a large number of experiments and analyses. A Campaign of Experimentation is defined as a "set of related activities that explore and mature knowledge about a concept of interest. A campaign of experimentation seeks to accomplish one or more of the following: focus attention on specific outcomes, accelerate progress toward one or more objectives, reduce risk; and make some progress more efficient. "[95] Thus, a Campaign of Experimentation was conceived as a way of focusing a diverse set of activities over an extended period of time and helping to ensure that the data generated was, to as great an extent as possible, comparable (comparable enough to permit cross-experiment analysis), and making experimentation more efficient. The formulation of a Campaign of Experimentation requires the articulation of the concept of interest, in this case C2 Agility, and a set of issues or hypotheses to be explored. The concept expressed as a conceptual model, defines the variables and relationships of interest and specifies the measures of success. As will be discussed in Chapter 8 - Findings, Conclusions, Way Ahead, SAS-085 formulated a campaign of experimentation focused on C2 Agility and provided an initial articulation of a conceptual model and set of Agility-related metrics in the hope that its initial efforts and results would encourage others to participate in a continuing campaign.

[95] Alberts and Hayes, Code of Best Practice: Campaigns of Experimentation, p.63

5.4 RETROSPECTIVE CASE STUDIES

The objective of each retrospective case study was to seek evidence for the C2ACMl, sub-concepts, variables, and variable relationships. Case study leads and their teams were asked to focus on characteristics of the approaches to C2 that were employed in given situations. Also, the case studies investigated how a C2 Approach may have changed as situation complexity changed.

While these case studies may provide enough information to help the readers understand the context and support the development of useful stories and vignettes that help communicate evidences for the C2 Agility concepts, they, on the other hand, do not always contain a description of all of the aspects of C2 (e.g., situational awareness, decision-making, planning, assessment, execution, etc.) unless these aspects help identify the C2ACM variables and their relationships.

Chapter 6 - CAMPAIGN OF EXPERIMENTATION FINDINGS

6.1 INTRODUCTION

A multinational Experimentation Team formulated a C2 Agility-related Campaign of Experimentation. It then designed and conducted a set of experiments to contribute to SAS-085's validation effort. This included testing the set of C2 Agility hypotheses previously identified with a variety of experimental platforms.

This chapter provides background and theory, explains the experimental methodology, the nature of the meta-analysis, reviews the hypotheses tested, and the corresponding experimental designs, and describes the experimental platforms used. It then presents results for each of the hypotheses and an overall summary of results.

6.2 BACKGROUND

Recent simulation-based experiments based on the work of SAS-065 and SAS-085 explored the relationship between C2 Approaches, the C2 Approach Space, C2 Agility, mission performance and the enablers of Agility. More specifically, Alberts (2011) introduced the notion of Agility Maps and associated metrics and, using the ELICIT environment[96], instantiated different NATO NEC C2 Approaches to explore the relationships between effectiveness, efficiency and Agility. In another study with ELICIT, Alberts & Manso (2012) reviewed the existing conceptual and theoretical foundations for exploring C2 Agility by considering the N2C2M2, C2 Agility Conceptual Model, Agility metrics, and an associated measurement process. Based on experiments designed and conducted using the enhanced experimental environment, abELICIT, it was determined that these foundations enable the systematic exploration of C2 Agility related hypotheses and in the process would improve the practice of C2 measurement and assessment. Similarly, Bernier (2012) exploited an experimental platform by reproducing an operational scenario based on a comprehensive approach, exploring two hypotheses: first, that more capable (more networked enabled) C2 Approaches provide higher levels of Agility; and, second, that the enablers of Agility are positively correlated with measures of Agility. Two additional experiments (Chan & Ivanic, 2010; Chan, 2010) assessed the impact on team performance of various aspects of trust and associated errors in information systems within a C2 context. Finally, Bruzzone et al. (2011) looked at how approaches to C2 impact mission performance in an asymmetric marine warfare context.

Each simulation-based experiment exploited an experimental platform (a constructive simulation tool configured in a specific way within the context of an operational or mission setting) capable of modeling several C2 Approaches (described in the N2C2M2) under a set of circumstances. In addition, the diversity of missions and scenario contexts offered by all the experiments presented a unique opportunity to test the same set of hypotheses in a broader context. Therefore, in order to produce a more complete, robust, and generalizable set of findings, rather than looking at the results of each single experiment in isolation, the SAS-085 Experimentation Team formulated a Campaign of Experimentation that employed a prospective meta-analysis across the multiple simulation based experiments, as explained below.

[96] Ruddy, M. (2007), "ELICIT – The Experimental Laboratory for the Investigation of Collaboration, Information sharing, and Trust, ICCRTS.

6.3 METHODOLOGY

Although conducting experiments (including simulation-based experiments) is commonplace, combining data from more than one experiment (not simply looking at the findings) is a more recent development.

The Code of Best Practice: Campaigns of Experimentation (Alberts & Hayes, 2005) and related literature do not specifically discuss how the results of a series of experiments can be integrated into a set of findings and reflected in modifications / extensions to a conceptual model. However, other research fields have investigated the ways that data from more than one experiment can be effectively utilized and provide guidance in this regard.

Mega-analysis, pooled analysis, and meta-analysis (Bravata & Olkin, 2001) are three methods for combining data and/or results from various experiments (Curran & Hussong, 2009). The ability to increase sample size and the variety of data has many advantages, including increased statistical power, reduced exposure to local biases, and in the case of meta-analysis, improved control of between study variations. SAS-085 Experimentation Team used meta-analysis for the C2 Agility Campaign of Experiments.

6.3.1 Meta-Analysis Method

Meta-analysis is a method that combines the results of multiple experiments with the objective of identifying patterns, similarities and disagreement among the results. Most meta-analyses are retrospective, i.e. they are based on already published studies, and use high-level findings such as the effect sizes as opposed to the data, since such data are usually not available. A single experimental run with human participants can be quite costly. For example, in an experiment a single run involves a selected C2 Approach under a specific set of circumstances. This constitutes one data point. In human participant experiments, the costs involve make it infeasible to accomplish more than a few such runs. This limits the number of combinations of C2 Approach and changes in circumstances that can be simulated. Simulation-based experiments require far less time and fewer resources for a single run and can generate a very large number of additional runs at a small marginal cost. Both types of experiments require considerable effort to design and setup in the case of human-in-the-loop experiments, or to develop and test the model in constructive simulation experiments. Both types of experiments can be designed with a meta-analysis in mind using an approach called prospective meta-analysis.

The meta-analysis approach in conjunction with the C2 Agility Campaign of Experimentation that has employed data generated from multiple experimental platforms used in various experiments, is an adaptation of prospective meta-analyses (Ghersi, Berlin, & Askie, 2011) conducted in the human and life sciences and applied to the domain of computer simulation. Simulation-based experiments offer the ability to explicitly control the environment and manipulate independent variables in such a way that it becomes possible to repeat an experiment under a large range of different conditions at minimal cost. However, a particular instantiation of a simulation model is limited in a number of ways, e.g. it may have a limited number of dependent and independent variables to draw on, it may have a reduced scope or it may be slow running limiting its utility for exploring the problem space. Using a set of simulation models instead of just one allows the experiment designers to consider undertaking a greater range of experimental runs. The advantages of using a prospective meta-analysis are the same as those associated with retrospective meta-analyses. However, prospective meta-analysis conveys an additional advantage because it is designed before the experiments are conducted. Prospective meta-analysis produces data that are more likely to be comparable rather than drawing on the data available from a retrospective meta-analysis, i.e. combining the findings of multiple past experiments. In addition, a prospective meta-analysis offers the opportunity to exploit the potential of the raw data which is not possible when combining high level results from a retrospective meta-analysis. In a prospective meta-analysis, since hypotheses are identified in advance, it becomes possible to generate data that are relevant and more complete for the selected set of hypotheses to be tested than it would be otherwise. It should be noted that a meta-analysis of multiple experiments must adhere to the same design process employed for a single simulation based experiment (Barton, 2004).

Undertaking a meta-analysis that employs multiple experimental platforms offers the following benefits:

- **Generalization**: a meta-analysis potentially increases the generalizability of the results by ensuring the uniformity in the hypotheses and in the variables is accounted for, while promoting exploration of a diversity of contexts with a range of different experimental platforms. Not only are results of a meta-analysis applicable to the study space that includes all of the circumstances that are considered in the set of model runs conducted, but they are also applicable to all of the in between contexts not explicitly tested (potentially a virtually infinite number of (sub)contexts that could have been created or chosen for this purpose).
- **Cross-Platform Results**: a meta-analysis offers better control for between experiment variations by explicitly considering the variation in fixed and random effects within the modeling due to the different instantiations of context and common independent variables. Thus, differences in results that would appear in various independent experiments are subtracted/removed, leading to more uniform, general, and meaningful results.
- **Power of Statistical Tests**: the meta-analysis increases the power of statistical tests that rely on the sample size[97] by combining data from many experiments. For instance, when the sample size is small, the differences observed cannot be established as not arising from random variations and thus the test may not be sufficiently discriminating.
- **Reduced Individual and Local Biases**: a meta-analysis reduces the influence of local biases. For instance, individual experimenters can choose inappropriate measures or unconsciously choose those that support their theories or the model that they employ may be biased towards favoring certain outcomes. Another potential source of error is that individual models or experiments could be open to criticism in some way. For example, the way a particular model is instantiated in a simulation may be flawed or the model or implementation may involve oversimplified assumptions. Other problems may be associated with data capture or mistakes during data manipulation. All of these errors could bias experimental findings. In a meta-analysis, these "random" unintentional errors are expected to cancel each other out, either partially or entirely, and thus produce less biased and higher quality results. A side effect of combining error is to increase variability and confound main effects with between-experiment variance, therefore a proper statistical model was chosen for dealing with this variability.
- **Promote Synergies, Interactions and Discussions Among Researchers**: A more subtle benefit of a prospective meta-analysis is to favor interactions and discussions as well as the setting of common goals among multiple researchers. The members of the Experimentation Team designed and conducted the experiments in close collaboration. This approach fostered highly critical thinking, helped challenge assumptions, and supported the generation of insights leading to proposals for

[97] Statistical power is proportional to the square root of the sample size.

alternative assumptions. In addition, designing and conducting a meta-analysis provided a formal and rigorous way to revisit SAS-085 concepts and it was in contrast to the usual white board exercises and workshops which are often less restrictive and do not encourage participants to strive for consistency. Moreover, the meta-analysis created fruitful interactions and helped to identify future research opportunities. The outcome of adopting this approach was not only a better designed set of experiments and associated meta-analysis but also a better shared understanding of the concepts under study.

6.4 OVERVIEW OF CAMPAIGN OF EXPERIMENTATION

SAS-085 Experimentation Team members from five NATO member nations (USA, Portugal, Canada, United Kingdom, and Italy) jointly developed and participated in a C2 Agility Campaign of Experimentation utilizing meta-analysis. A number of different simulation models and platforms were employed and, in the case of one experimental platform, different members design and conducted experiments with different sets of conditions.

The first step in the formulation of the Campaign of Experimentation involved the specification of a common reference model (here the C2ACM), a set of hypotheses derived from the model, the controllable variable(s) of interest (here the C2 Approaches), other independent variables (e.g. missions and circumstances) and dependent variables (e.g. observed behaviours) including measures of merit (e.g. effectiveness score), and a preliminary experimental plan. The second step involved conducting a series of experiments by each participating nation, with each using their particular experimental platform or simulation model, each using a unique, but comparable experimental design and a subset of the variables of interest in accordance with the formulation of the campaign to explore a range of C2 Approaches. The third step involved the collection of data from these experiments which was then merged and analysed according to the meta-analysis plan. These steps and the initial set of experiments are depicted in Figure 6.1: Campaign of Experimentation (Initial Phase). The Campaign of Experimentation is expected to be continued as SAS-085 members pursue their research interests and as others are attracted to the exploration of C2 Agility. The subsections that follow discuss these steps in greater detail.

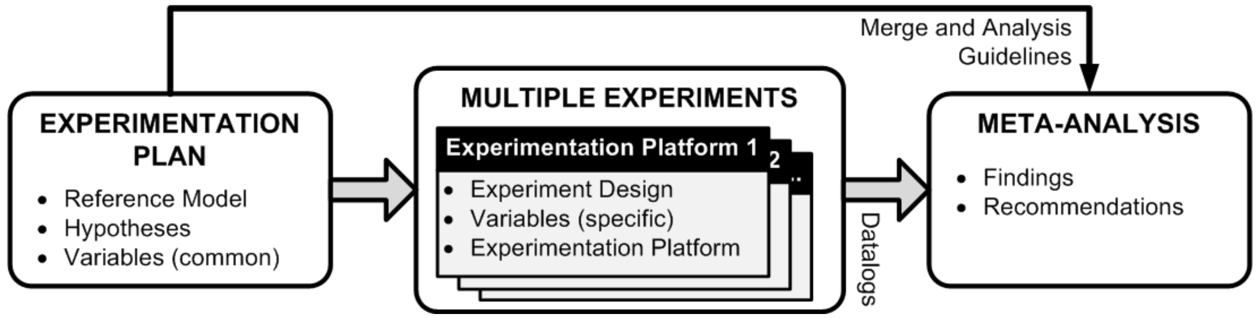


Figure 6.1: Campaign of Experimentation (Initial Phase).

6.4.1 Selecting Experimental Platforms

Experimental platforms and the simulation models they employ are usually verified and validated for a given domain and within a limited set of experimental conditions (Sargent, 1994). Consequently, only experimental platforms with a track record of undertaking C2 Approach-related assessments were included as candidates for our Campaign of Experimentation. Having established a particular platform's appropriateness for C2 experimentation, we sought to ensure that the platform could instantiate at least two (preferably all) of the NATO NEC C2 Approaches as well as more than one circumstance. Finally, we required that the platform was capable of measuring success and the time required to achieve it.

The nature of the mission challenge was not standardized, nor was the definition of the measure of success. These differences across the experimental platforms presented some challenges when it came to combining their outputs to produce meaningful analysis. Meta-analysis provided the tools to meet this integration challenge.

There are a number of ways that one can select experimental platforms for a Campaign of Experimentation. One could use a waterfall (or top-down) process that begins with the objectives of the Campaign of Experimentation as expressed in the form of the specific hypotheses identified. However, this approach has proven to be impractical given (i) the preliminary nature of the C2ACM (at the time when SAS-085 was formulating our Campaign of Experimentation) and (ii) the limited resources and time available. Even if a more mature model and adequate resources and time were available, a top-down approach requires a large number of experimental platforms from which to choose to ensure finding those with conditions of validity compatible with the aims of the meta-analysis.

As a consequence, SAS-085 used an iterative process since it offered more flexibility. The Experimentation Team began by formulating a set of candidate hypotheses keeping in mind the campaign's general objectives. The next step was to identify the variables of interest, those needed to test the hypotheses. This provided the specific criteria to be used in our assessment of candidate experimental platforms. The Experimentation Team looked for platforms that were capable of representing, manipulating, and instrumenting the observable variables of interest. Once this assessment had been completed the objectives and hypotheses were revisited and a further refinement was undertaken, including the addition of more hypotheses, based on the improved understanding as to the capabilities of the available experimental platforms.

The assessment identified that some experimental platforms lacked the capability to test some of the hypotheses. Given the lack of alternates available, it was decided to include platforms even if they were unable to contribute data that could be used to test all of the hypotheses and rely upon the power of the meta-analysis to cope with the asymmetries this created. Thus, not all of the experiments contributed data for all of the hypotheses. While, in theory, this should enable us to capitalize on the strengths of the available experimental platforms, while minimizing the effect of any model's weaknesses, in practice, this was the most challenging aspect of the design and conduct of the meta-analysis.

SAS-085 selected a total of six constructive simulations[98] to employ in the C2 Agility Campaign of Experimentation. These six had been previously used to conduct at least one experiment whose objectives were compatible with those of SAS-085's experimental campaign. The simulations that provided data for the meta-analysis were: ELICIT-IDA (USA), ELICIT-TRUST (USA), abELICIT (Portugal), IMAGE (Canada), WISE (UK) and PANOPEA (Italy). The following paragraphs briefly describe each of these experiments.

6.5 ELICIT

6.5.1 ELICIT Overview

The Experimental Laboratory for the Investigation of Collaboration, Information-sharing and Trust (ELICIT) platform (Ruddy, 2009, 2011) was originally developed by DoD's Command and Control Research Program (DoD CCRP at www.dodccrp.org) to facilitate the testing of hypotheses related to edge and hierarchical (traditional) approaches to C2. ELICIT is a virtual instrumented environment where human are connected over a configurable network to accomplish assigned tasks. ELICIT can be used to empirically explore the relationship among approaches to C2 and organization, team and individual characteristics and value related measures that constitute the network-centric value chain. ELICIT has been enhanced with the addition of software agents that can 'stand in' for human participants. When all of the participants are agents ELICIT can run faster than real time and is referred to as abELICIT. Three applications of abELICIT have been used in support of SAS-085's Campaign of Experimentation. ELICIT-IDA (Alberts, 2011) and abELICIT (Alberts & Manso, 2012; Manso & Manso, 2010; M. Manso & Nunes, 2008; M. Manso, 2010) were both used to explore the relative Agility of four C2 Approaches. Success for the simulated shared awareness task was defined as satisfying a combination of correctness and timeliness requirements (how many individuals correctly solved the problem, and the time they required). Efficiency was also measured. The C2 Approaches were evaluated using a variety of mission challenges and stresses which are different for ELICIT-IDA and abELICIT. The third application of ELICIT, ELICIT-TRUST is a variant of abELICIT in which the agents evaluate the behaviour of other nodes and generates an estimate of trust for those agents with which it interacts (Chan & Adali, 2012; Chan, Cho, & Adali, 2012). Trust is evaluated based on the willingness of another agent to provide information and the competence of the agent to provide valuable information. Based on these estimates of trust, agents adapt their behaviours as they

[98] Constructive simulation is defined as modeling and simulation involving simulated people operating simulated systems.

interact with the other agents seeking to interact with the most trustworthy agents and with the goal of maximizing mission performance.

6.5.2 ELICIT Scenario

All ELICIT applications for SAS-085 used a scenario challenging human participants or software agents to find the Who, What, Where and When of a terrorist attack. Throughout the course of the experiment, factoids (i.e., information elements that are pieces of the puzzle) are distributed to participants or agents. If permitted to do so by the configuration of their organization and approach to C2, participants or agents may (or may not) disseminate factoids to other participants or agents by sharing information and collaborating using this instrumented platform. However, only by sharing information can they achieve sufficient levels of awareness to solve the problem completely. The challenge in ELICIT is unambiguous and clear: it has a clearly defined objective and all information is accessible. Moreover, the Factoid Set (i.e., the set containing all factoids) has no ambiguity among the factoids and it does not contain erroneous information. Nonetheless, the dynamics caused by human participants or agents during the runs, as well as their behaviours, results in complex behaviours. For example, the order in which factoids are received by agents (in turn, a function of individual agent decisions) affects the final results.

6.5.3 ELICIT Implementation of C2 Approaches

The three ELICIT applications instantiated C2 Approaches following the organizational options depicted in Figure 6.2: Description of C2 Approaches Elicit – Extracted from (Alberts, 2011). However, each experiment implemented slightly different variations of these organizations by, for example, changing the number of team members and leaders. They also differed in how they defined acceptable performance or 'success.' For example, ELICIT-IDA maintained the same measures of effectiveness (number of individuals who correctly solved the problem and the time it took for the first correct solution to be developed) for all C2 Approaches and used mission requirements as the standard for determining success, while abELICIT evaluated success differently for each C2 Approach. In runs where the entity employs either a Conflicted or a De-Conflicted C2 Approach, success depended on the ability of all team leaders to solve the problem. When a Coordinated C2 Approach was employed, organization success depended on the coordinator finding the correct solution. When a Collaborative C2 Approach was employed, organization success depended on the coordinator finding the correct solution to all problem spaces or team leaders finding the correct solution to their problem space. Finally, when an Edge C2 Approach was employed, organization success depended on a plurality of individuals being correct in for aspect of the problem.

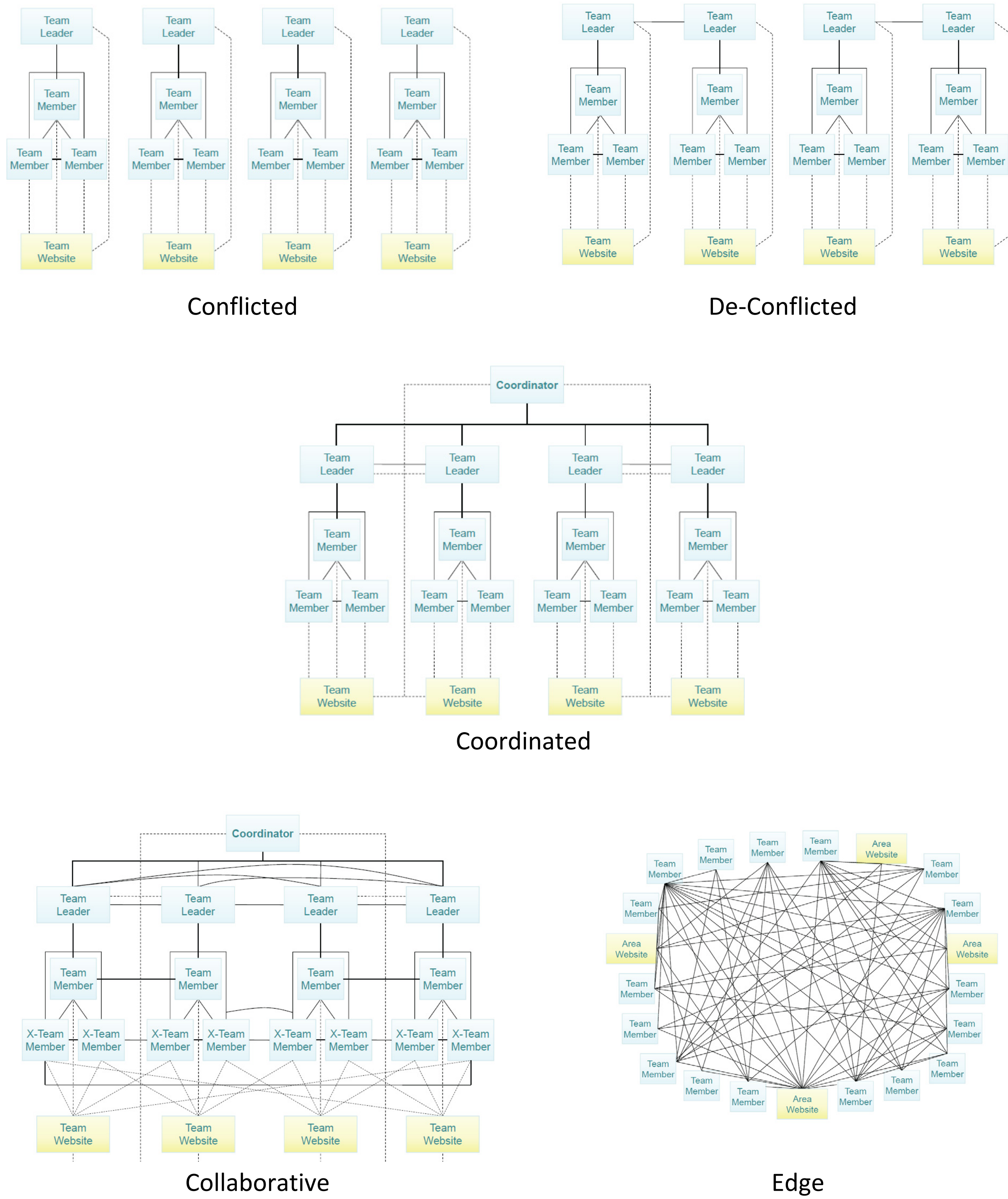


Figure 6.2: ELICIT Instantiation of C2 Approaches – Extracted from (Alberts, 2011)

6.6 IMAGE

6.6.1 IMAGE Overview

IMAGE (Lizotte et al., 2008; Lizotte, Bernier, Mokhtari, & Boivin, 2013) was developed as a suite of generic representations, “scenarization”, simulation and visualization tools aimed at improving the understanding of complex situations. More recently, a simulation-based experiment was designed with IMAGE to investigate how C2 Approaches instantiated in a specific operational context impact Agility and mission effectiveness (Bernier, 2012). IMAGE represents organizations that are implemented by software agents that deliberate and act according to rules that comply as much as possible with N2C2M2 theory.

6.6.2 IMAGE Scenario

The scenario chosen for SAS-085 simulates a failing state that has experienced years of civil war and conflicts with a neighboring country. The central government and local authorities have been struggling with rebels, refugees, poverty, and starvation for many years. The simulation begins with the arrival of the international community involving the military, other government departments (OGDs), and non-government organizations (NGOs). Their mandate is to secure and stabilize the failing state. Each organization within the scenario conducts activities according to their area of responsibility. For example, a military organization is responsible for providing security for economic development or humanitarian activities being conducting by NGOs. As per reality, the scenario is designed such that cooperation between organizations significantly improves the likelihood of success. The consequences of cooperation are less conflicting actions and higher levels of synergy. Such an approach is called comprehensive (Leslie, Gizewki, & Rostek, 2008). The IMAGE experimental platform supports a variety of challenges/circumstances within the scenario, including information sharing delays, organizations that retract unexpectedly, enemy strengthening, and surges in crisis severity. The combination of all these changes produces a scenario that represents an Endeavour Space comprising 54 circumstances. Each C2 Approach is exposed to the whole Endeavour Space, thereby revealing their comparative advantages and their weaknesses in term of C2 Agility which in turn supports the assessment of the hypotheses.

6.6.3 IMAGE Implementation of C2 Approaches

IMAGE instantiated each of the C2 Approaches by configuring the ADR, PoI, and DoI between organizations. Figure 6.3: IMAGE Instantiation of C2 Approaches provides a description of how the Collective implemented each C2 Approach. More details are provided in (Bernier, 2012).

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 D*e-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.

Figure 6.3: IMAGE Instantiation of C2 Approaches

6.7 WISE

6.7.1 WISE Overview

The Wargame Infrastructure and Simulation Environment (WISE) (Pearce, Robinson, & Wright, 2003) is a Land focused C2 model with representation of air and maritime support to Land operations at the system level. WISE represents warfighting and currently in a limited capacity peace support or stabilization operations, operating either as human in the loop wargame or as a closed form constructive simulation. The basic conceptual framework within WISE is built around organizations that are used to represent either individual

Entities, such as a single tank, or aggregated units, such as a company. A scenario typically instantiates a mixture of the two with the wargame being used to provide the basis for follow on constructive simulation runs. Within WISE organizations are sufficiently generic in nature to allow for a wide range of scenario actors to be represented. For example an organization can represent an individual platoon, unmanned air vehicle, improvised explosive device, insurgent force, civilians etc. WISE is a C2 centric model in that it has a detailed representation of communications and networks and the information flows across these networks leading to the development of a perception against which an organization makes decisions. These perceptions are measured to determine the level of situation awareness present at an organization thereby enabling studies of C2 by examining the impact of changes in C2 capability through the measures of merit hierarchy (Fellows, Pearce, & Moffat, 2010). The C2 centric nature of WISE combined with the representation of communications and networks enables a number of changes of circumstances, i.e. perturbations or enhancements to C2 to be represented.

6.7.2 WISE Scenario

The scenario chosen for SAS-085 is similar to that chosen for IMAGE with WISE simulating 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. This task falls to a single battlegroup with other battlegroups performing security and isolation tasks. The simulation represents a range of complex issues, including civilians, insurgent attacks across the area of operations and a range of other de-stabilizing actions ensuring a dynamic and complex scenario. Success for the UK brigade is the defeat of insurgents within the urban area.

6.7.3 WISE Implementation of C2 Approaches

Two C2 Approaches were represented within WISE, De-Conflicted and Collaborative. The representation of De-Conflicted C2 within WISE represented patterns of interaction and the distribution of information organized along boundaries and areas of responsibility, i.e. each battlegroup was assigned its own Area of Operation (AO). The C2 links between sub-units and battlegroup HQ and between battlegroup HQs and brigade HQ were hierarchical with no peer to peer links to other battlegroup HQs. ADR was represented through joint fires assets being controlled at both battlegroup HQ and brigade HQ with mortars at company HQ, i.e. there was no sharing of pooled resources. Finally, the rules of engagement were tightened to represent reduced availability of information and hence more uncertainty in the targets being selected for engagement. The representation of Collaborative C2 within WISE represented patterns of interaction and the distribution of information up the command hierarchy as in the De-Conflicted approach but also peer to peer links across company HQs and battlegroup HQs. ADR was represented through joint fires assets being shared and resources pooled at brigade HQ to enable targets to be prioritized across the different battlegroup AOs. Mortars however were still held at company HQ. Finally, the rules of engagement were relaxed to represent greater availability of information and hence more certainty in the targets being selected for engagement.

Figure 6.4: WISE Instantiation of C2 Approaches depicts the way the different C2 approaches were implemented in WISE.

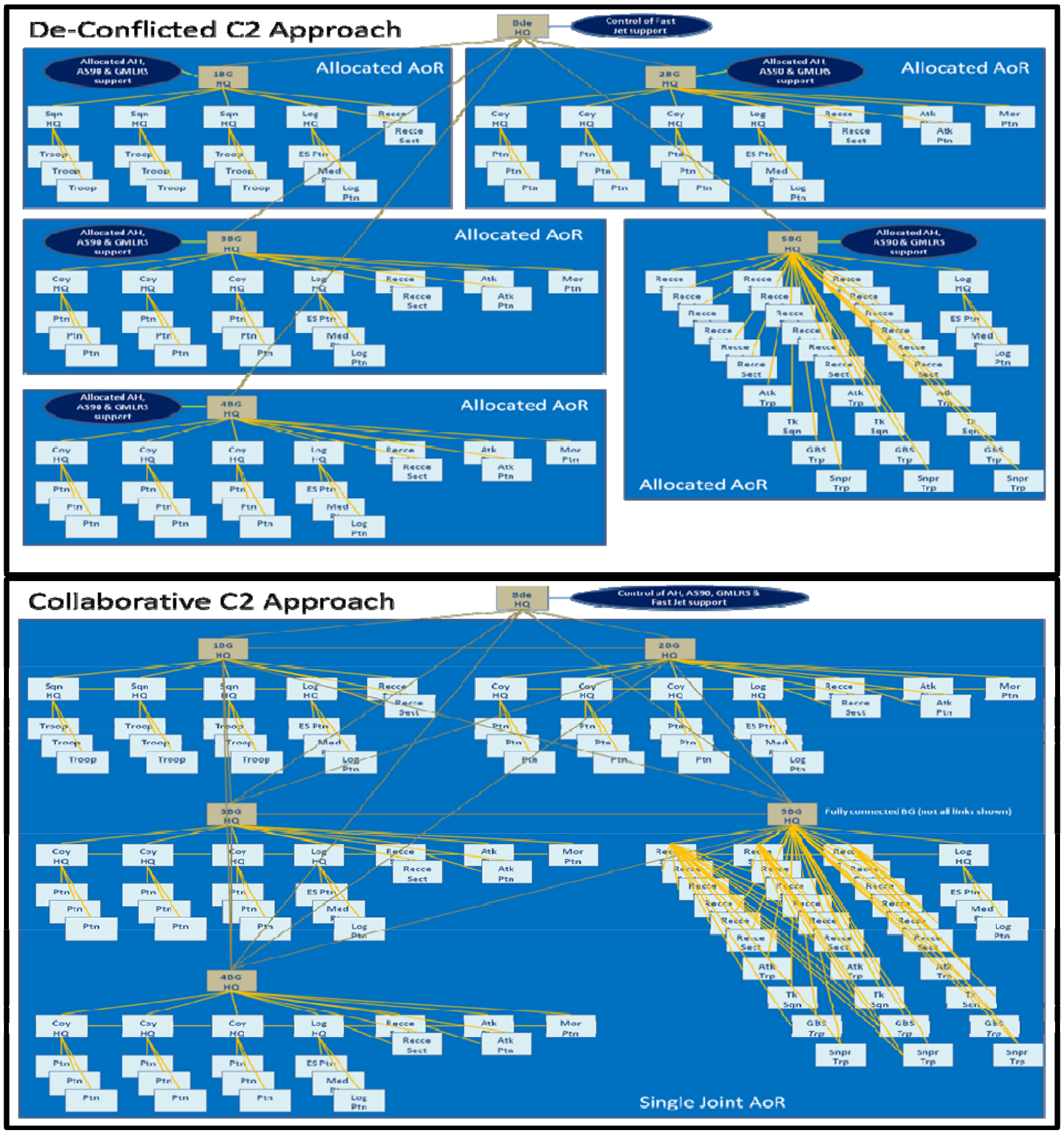


Figure 6.4: WISE Instantiation of C2 Approaches

6.8 PANOPEA

6.8.1 PANOPEA Overview

The Piracy Asymmetric Naval Operation Patterns modeling for Education & Analysis (PANOPEA) (Bruzzone, Massei, et al., 2011; Bruzzone, Tremori, & Merkuryev, 2011) is an agent based simulation that directs IA-CGF (Intelligent Agents Computer Generated Forces) through the application of a range of strategies and based on their situation awareness to successfully defeat pirates. PANOPEA allows different C2 Approaches to be instantiated. For example, in this series of experiments, De-Conflicted, Collaborative, and Edge C2 Approaches were instantiated. PANOPEA supports the SAS-085 experimental objectives by modeling different C2 Maturity Levels according to the N2C2M2 theory and supports the extraction of a range of measures of merit for assessing the effectiveness and efficiency of the proposed C2 Approaches in order to investigate the Agility of the C2 solutions and their influence in preventing pirate attacks by implementing different policies and different organizational models.

6.8.2 PANOPEA Scenario

The scenario chosen for SAS-085 was a piracy scenario set in the Horn of Africa, a critical area in terms of the effect that pirate attacks have against cargo ships. The scenario includes naval vessels and helicopters, intelligence assets, ground bases, cargo ships, other boats (i.e. fishing boats and yachts) as well as pirates hiding in the general traffic. The simulation represents a range of complex issues, including pirate attacks on navy and cargo vessels, information flows and actions by friendly forces to deter or defeat pirate attacks. In a way that is similar to the other experimental platforms, PANOPEA supports a wide variety of challenges/circumstances, including variations in decision-making capabilities, weather conditions, the effect of misleading information and the number of pirates. Altogether, these create a complex Endeavour Space against which each C2 Approach can be tested.

6.8.3 PANOPEA Implementation of C2 Approaches

PANOPEA instantiated three C2 Approaches: De-conflicted, Collaborative, and Edge. The PANOPEA scenario for SAS-085 experimentation was designed with two Coalitions operating in the area. Frigates were controlled through a command chain. Information was provided by ship intelligence, cargo vessels and local authorities. Actors having different roles interact and take decisions according to the pre-determined configurations illustrated in Figure 6.5: PANOPEA Instantiation of C2 Approaches. The level of connectivity increases when moving from De-Conflicted to Collaborative and from Collaborative to Edge.

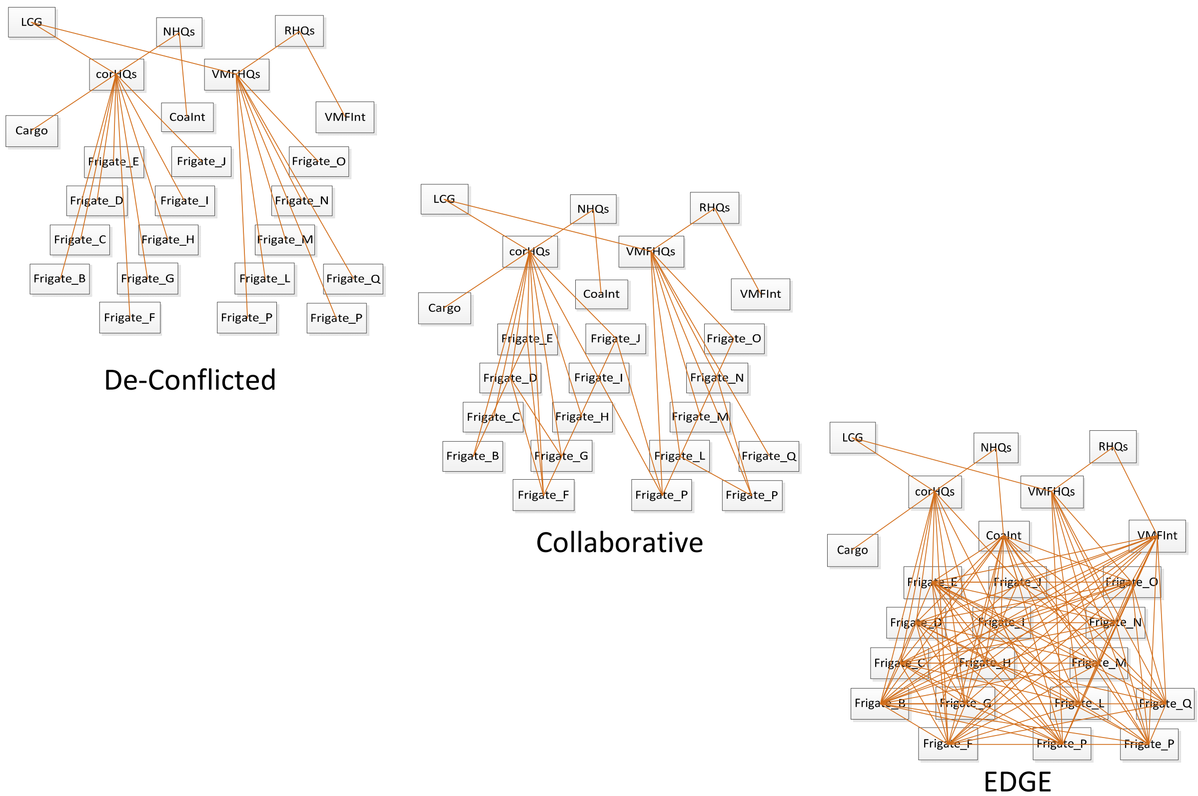


Figure 6.5: PANOPEA Instantiation of C2 Approaches

6.9 DATA FOR THE META-ANALYSIS

To facilitate the merging of data from each experiment it was necessary to undertake the important task of predefining and documenting the independent and dependent variables with the aim of establishing a clear audit trail and ensuring a common understanding across the Experimental Team. The first step consisted of deciding which dependent variables (MoM) were needed to test the hypotheses and which independent variables were appropriate for determining their effect on the dependent variables. The viability of measuring the dependent variables of interest depended on the experimental platform. In some cases, experimental platforms measured independent and dependent variables using different scales and an understanding had to be established to determine the degree of correspondence across these difference scales. Normalization across the scales helped to mitigate differences in the way variables were measured across the experimental platforms. The modelling of effects, described in the experimental design section, provided an additional and even more efficient way to manage these differences. As for selecting appropriate variables and the range(s) of values that they should take on, two approaches were used to simplify the task and add rigor to the process.

One approach was to identify theories and definitions that reflected the concepts underlying a variable. For instance, there is an important corpus of literature about how situational awareness and shared situational awareness should be measured. Many of them explain how they relate to each other. Some definitions of situational awareness emphasize the completeness and granularity of awareness while others emphasize timeliness. The literature provides explanations regarding the relationships between these two aspects of awareness. Existing definitions of variables and examples of how these variables have been measured were used to guide the development of compatible MoM's for the meta-analysis. C2 Approach is the major controllable factor of interest in the C2 Agility Campaign of Experimentation. The six experiments employed each based their instantiation of particular C2 Approaches on the descriptions and graphic depictions provided by the N2C2M2. The SAS-085 Experimentation Team went beyond the information provided by the N2C2M2 to develop quantitative measures of ADR, PoI, and DoI to more accurately position the simulated C2 Approaches in a common C2 Approach Space.

A second consideration in settling definitions and metrics for variables to use for the meta-analysis involved the trade-off between variability and uniformity. In the previous example, uniformity was stressed to facilitate the testing of hypotheses related to one or more C2 Approaches. That is, the data can be merged because each experiment has essentially the same instantiation of each C2 Approach. However, it is important to understand that a specific C2 Approach does not equate to a point in the C2 Approach Space, but a set of points or a region. Therefore, as SAS-085 sought to represent C2 Approaches in the different experimental platforms, it made sense to permit, even to encourage, some variation in the way any given C2 Approach is instantiated as long as it falls within the region associated with that C2 Approach. This reflects the natural variability found in the real world and improves the external validity and robustness of the findings of the meta-analysis. This allowed us to test how well a set of typical interpretations of a given C2 Approach performs given an Endeavour Space. For instance, testing the Agility of an organization was accomplished by measuring how well it performed against a wide range of circumstances, the sum of which constitutes an Endeavour Space. The Endeavour Space is experiment specific because it depends on the mission and situation being simulated, e.g. a degraded network for a network centric warfare-related mission.

The design of individual experiments, their particular instantiations of C2 Approaches and Endeavour Space, ensured that there would be a large amount of variability and variety across the experiments. Although this is inherent in a meta-analysis the scale here was far greater than that of a set of experiments that employed identical treatments (in this case two or more C2 Approaches) across a set of constructive simulations. The data generated for SAS-085's meta-analysis represents a number of different instantiations of the NATO NEC C2 Maturity Model C2 Approaches and a variety of missions and circumstances associated with the different constructive simulations. The resulting variation in the design of experiments was itself a confounding variable nested within the experiment, e.g. *Circumstance* within experiment.

To instantiate a given C2 Approach and locate it within the C2 Approach Space, one must decide how to measure the dimensions of this space: ADR, PoI, and DoI as articulated in the C2 Conceptual Reference Model. There are many ways to define and scale these dimensions and the theory does not specify a particular way at this point in its development. For example, any metric that aims to capture the essence of the DoI concept would certainly have to incorporate many aspects related to the quality of information for each individual in the organization. These would include completeness, correctness, precision, etc., and their values as a function of time. Each experiment, therefore, had to consider how to quantify a scale related to each of the three dimensions of the C2 Approach Space. The variation that results will, in fact, become an advantage in the meta-analysis, making the conclusions more widely applicable.

6.10 INDEPENDENT VARIABLES

Three independent variables or factors were considered, *C2 Approach* (a fixed effect)*, Circumstance* and *Experiment* (random effects). As discussed earlier not all of the experiments implemented all of the C2 Approaches, thus the resulting design was non-balanced, i.e. values were missing for some combinations of levels of *C2 Approach* and *Experiment*. For this reason, the average values of the outcome (dependent) variables such as *Agility Score* were not computed as the arithmetic mean but instead as the least squares (LS) mean, or estimated marginal means. LS-means represent the mean response for each factor adjusted for the *Experiment* variable in the statistical model, including missing values.

The first independent variable considered within the meta-analysis was *C2 Approach*. Despite variation in the design and instantiation of C2 Approaches across the different experiments this variable was considered identical from a statistical analysis perspective. Five different C2 Approaches were implemented across the experiments: Conflicted, De-Conflicted, Coordinated, Collaborative and Edge. An experimental condition, or simulation run, consisted of an instantiation of an experimental platform *(Experiment)*, a specific region of the Endeavour Space *(Circumstance*) and from two to all five of the pre-defined C2 Approaches (treatments) to generate their samples.

The specific C2 Approaches instantiated in each of the six experiments are shown in Figure 6.6: C2 Approaches and Experiments. Although each implementation of these C2 Approaches was different, verifications were conducted to ensure that as far as possible they were equivalent across all experiments and all complied with the theoretical concepts articulated within the N2C2M2. As it turned out, two of these instantiations were judged as too dissimilar and were dropped before any analysis was conducted.

	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

Figure 6.6: C2 Approaches and Experiments

The second independent variable considered in the meta-analysis was *Circumstance* which represented a series of challenges and conditions within an operational or mission context, each of which could occur. Two categories of circumstances were implemented across the experiments: changes to Self and changes to *environment*. The *Circumstances* populating the Endeavour Space include various states of degraded and/or denied Self or environment as well as other challenges that cause effects similar to degradations in Self or the environment.

The primary role of *Circumstance* is to deduce Agility, i.e. the proportion of the mission/challenges for which a Collective is successful. However, *Circumstance* serves two additional purposes. First, *Circumstance* corresponds to what is called a noise factor in the literature (Steinberg & Bursztyn, 1998). Such factors aim to recreate the natural variability found in the real-world and correspondingly improve the external validity and robustness of the findings. Second, incorporating a large quantity of circumstances reduces the probability of selecting a set of circumstances that would be biased, that is systematically detrimental or beneficial to some C2 Approaches (law of large numbers), i.e. incorporating a large number of changes in circumstances enables a larger sampling of points in the Endeavour Space to be included. This makes the Agility score a better estimate of the population mean.

The meta-analysis utilized all of these points (Figure 6.7: Experiment Endeavor Spaces Conditions). abELICIT looked at an Endeavour Space that had less dimensionality than, for example, ELICIT-IDA.

The Collective Endeavour Space consists of 22 circumstance variables, giving a total of 231 different problem challenges (mission / conditions) or 231 points in the Collective Endeavour Space. This number is far greater than any one individual experiment could practically achieve, and provides a good example of where diversity in the independent variable pays off. Additional model runs were considered but were not made due to insufficient time available to simulate them all.

	ELICIT-IDA	ELICIT-TRUST	abELICIT	IMAGE	WISE	PANOPEA
Self	Network damage (3)	Message/Drop rates (3)	Infostructure degradation (2)	Latency (3)	Bandwidth efficiency (3)	
		Trust (3)	Agent performance (3)	Missing org (2)		Ship decision-making capability (2)
		Selfishness (3)	Organisation disruption (2)			Intelligence DM capability (2)
Environment	Challenge (4)		Key info. available (3)	Number of rebels (3)	Comm. link quality (2)	Number of pirates (2)
	Noise in information (3)			Crisis severity (3)		Weather condition (2)
	Cognitive complexity (3)					Misleading information (2)
#	108	27	6	54	54	32

Figure 6.7: Experiment Endeavor Space Conditions

The final independent variable considered in the meta-analysis was *Experiment,* an implicit independent variable. The *Experiment* variable (incorporating all of the attributes of a given experimental platform including the problem, agent behaviours and agent interactions) is of little interest in itself but was nevertheless captured because it represents a sample of a virtually infinite population of experiments, with their associated experimental platforms, that do not exist yet but that could be created with the same purpose as this meta-analysis. By treating the experiments in this way the findings from these six experiments can be generalized to an infinite number of experiments with the same objectives.

6.11 DEPENDENT VARIABLES

The values of many dependent variables were measured for each run (combination of *C2 Approach* and *Circumstance*). The first dependent variable, *Mission Success*, is a normalized value representing the success or failure of the mission and provides an input to the calculation of an Agility score. Thus it is an intermediate variable or link in the Agility value chain. The Agility of a Collective operating under a given C2 Approach was measured by the proportion of the Endeavour Space in which the Collective was successful. This value is called the *Agility Score* and was calculated by averaging the values of *Mission Success* associated with all of the simulation runs for a given C2 Approach.

The next three dependent variables are metrics that estimate the actual position of a Collective in the C2 Approach Space. This position is a function of what was intended and how it was impacted by the mission and circumstances. For example, setting up a simulation to represent a given C2 Approach Space is designed to achieve a certain pattern of interaction and/or distribution of information. However, the actual flows of information can be adversely affected by a change in circumstance (e.g. network outage). By comparing the actual to the intended positions in the C2 Approach Space we can determine if a Collective is able to maintain its intended position within the C2 Approach Space and, if not, it is possible to measure the difference from the intended position. In all of these simulations, the value of ADR is unaffected by circumstances. However, the selection of a value for ADR does have a great impact on the measures of success and Agility. Once set, ADR, is not changed in these simulations. Thus, the capability of Entities to maneuver in C2 Approach Space is not represented. This potentially makes some choices of ADR, either because of a mismatch for the mission / circumstances or not in line with PoI and DoI, result in low probabilities of success and low Agility scores. Additional discussion about intended v. actual positions in the C2 Approach Space is available in (Alberts, Bernier, Chan, & Manso, 2013) and is considered in relation to Hypothesis H7.

The conceptual model of the N2C2M2 does not provide any guidance concerning methods of measurement or how to operationalize the model for experimentation purposes. Thus, one of SAS-085's tasks was to make the C2 Approach Space more useful to both researchers and practitioners by considering ways to quantify the dimensions of the C2 Approach Space. The challenge for undertaking the meta-analysis was to select one or more variables among those already captured by each experiment, given that each experiment instantiated different proxies (metrics) to characterise each of the approach space's dimension. The various instantiations of these measures was an advantage in that it enabled a range of perspectives as to how to characterise these dimensions to be considered. Figure 6.8: C2 Approach Space Dimension Metrics shows the definition of measures used in the experiments to measure ADR, PoI, and DoI.

Experiment	ADR	PoI	DoI
ELICIT-IDA	Amount of individuals with decision rights divided by total number of individuals.	Scaled square root of number of information related transactions (post, pulls, shares).	Average percentage of factoids received by each individual.
ELICIT-TRUST	Amount of individuals with decision rights divided by total number of individuals.	Average number of links used.	Average percent of factoids received by each individual.
abELICIT	Amount of individuals with decision rights divided by total number of individuals.	Average network reach of each individual.	Average information accessed by each individual.
IMAGE	Number of decisions allocated to the Collective divided by the total number of possible decisions.	Sum of all co-conducted activities between organizations divided by the sun of all conducted activities.	Normalised difference between all variables values known by all individuals and the ground truth.
WISE	1-Betweeness Centrality	Mean of the (normalised value of Socio-metric status) + (1-Bavelas-Leavitt centrality) + Inverse path length + Clustering score / 4	Mean HQ SA scores + (1-Eigenvector Centrality)).
PANOPEA	All the information taken directly by frigates and helos.	Total number of communications among actors divided by number of alerts from intelligence	Average number successfully received alerts against the total number of sent alerts.

Figure 6.8: C2 Approach Space Dimension Metrics

6.12 META-ANALYSIS DESIGN AND ANALYTICAL APPROACHES

Two sources of randomness had to be dealt with as part of the meta-analysis. The first source of randomness was due to the "randomly sampled" subset of circumstances forming an individual experiment's set of points in Endeavour Space that constitutes a small sample from a virtually infinite Endeavour Space. The second source of randomness was the experiment itself with differences in the problem or scenario and the manner in which the C2 Approaches were instantiated. Both random variables were likely to cause the values of ADR, PoI, and DoI that were observed to be distributed over a large range of values. The consequence of this randomness and the broad range of likely values is that comparing mean values of ADR, PoI, and DoI for any pair of C2 Approaches was insufficient to sustain a claim that there was a real effect from one value being higher or lower than another, i.e. that they were located in different regions of the C2 Approach Space. This is because the difference observed might be due to randomness during the "sampling". To overcome these limitations hypotheses were tested with an analysis of variance using a mixed effect model (*Experiment* was the random variable and *C2 Approach* the fixed effect).

It is important to establish an explicit statistical model (not to be confused with the conceptual model) for the meta-analysis, one that provides the foundation for analysis across all the experimental runs. The purpose of a statistical model is to establish relationships between and among the variables of interest, the validity of which is important for the hypotheses under test. Experimental results not only serve to sustain/disprove hypotheses but also help to improve the statistical model by estimating values for parameters. Since some of the independent variables in this meta-analysis are probabilistic, a statistical test is appropriate. The family of statistical models (e.g. linear regression) and tests (e.g. student t) available is vast. The choice of which statistical models and tests to use depends on the number and types of dependent and independent variables, the type of distribution of values observed for dependent variables, and the relationship between and among variables (linear, quadratic).

As described above the *C2 Approach* independent variable was fixed with the C*ircumstance* independent variables considered random. *C2 Approach* was deemed to be a fixed effect because the only levels of interest were those explicitly agreed upon for inclusion in the experiment. *Experiment* on the other hand is a random effect because it represents a "sampling" of an infinite number of possible experiments that may be of interest to test. In other words, controlled or observed values of this variable constitute a sample from a larger population of values. The heterogeneity[99] of the meta-analysis is an undesired property and is likely to occur because the SAS-085 experiments differed in many aspects. Random effect models deal with this heterogeneity, therefore *Circumstance* was considered a random variable due to the differences between and among the experiments. Because one independent variable was random and another one was fixed the linear mixed model was used.

The meta-analysis combined both fixed and random effects in its design, requiring what is called a mixed model for its analysis. In such a model the *Experiment* independent variable is defined as a block[100]. Blocks are groups of experimental units that are similar. By including blocking in a meta-analysis, the model captures the variability between and within blocks (experiments) and can better estimate the impact of the fixed effects on the dependent variable(s). Due to the possible difficulty of comparing measures taken from different

[99] When there is more variation between the studies being included in a meta-analysis than what is expected by chance alone.

[100] The term block takes it origin from the early ages of experimentation. Blocks where designated plots of land where various fertilizers or seeds where tested. Since plots may have had different intrinsic yields (e.g. due to better drainage), blocking allowed for subtracting the effect of the intrinsic yield of the plot from the total effect, leaving only the fertilizer or seed effect.

experiments, like the average Agility scores, a mixed model with *C2 Approach* as a fixed effect and *Experiment* as a random effect subtracts any variability due to the experiment. It would have been possible for *Experiment* to be considered a fixed effect, even if it was not part of the treatment, but by doing so findings would have been specific to the limited situations represented by the set of experiments included in the meta-analysis. With *Experiment* modelled as a random variable, findings can be applied to an infinite population of similar experiments or experimental platforms.

6.13 EXPERIMENTAL FINDINGS

The following section presents the results of the meta-analyses for each of the hypotheses.

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

The first hypothesis, that the C2 Approach Space provides a useful way of characterizing and depicting the differences between and among C2 Approaches, depends upon the ability to accurately locate the position of a given C2 Approach within this space. Figure 6.9: Positions in the C2 approach Space depicts the actual positions in the C2 Approach Space for each of the simulation runs (values of ADR, PoI, and DoI for each of the six sets of experimental runs. These runs represent the results of the outcomes associated with each C2 Approach and mission/circumstances instantiated in each experiment. In each experiment, the least stressing set of circumstances was chosen to serve as the baseline. Thus, the other circumstances simulated were more stressing conditions, such as degraded networks or more noise in the information. This provided an opportunity to highlight the impact that more difficult challenges have on both the observed position in the C2 Approach Space and outcome measures. Readers should note that the positions in the C2 Approach Space for each of the C2 Approaches differ across the experiments. In addition, the relative spread (size of the region covered by a given C2 Approach) also varies considerably. The differences in the missions that are simulated and in the nature of the circumstances tested in each experiment explain, in large part, these observed differences. As discussed previously, such variation represents the diversity of the points in the Endeavor Space included in this meta-analysis. Computing the mean values corresponding to the location of each circumstance for each C2 Approach would not be appropriate because the points used to compute the mean are randomly distributed and randomness in the selection of those independent variables may explain the observed results. Consequently, these differences had to be accounted for in the statistical models (mixed linear model) to improve statistical significance.

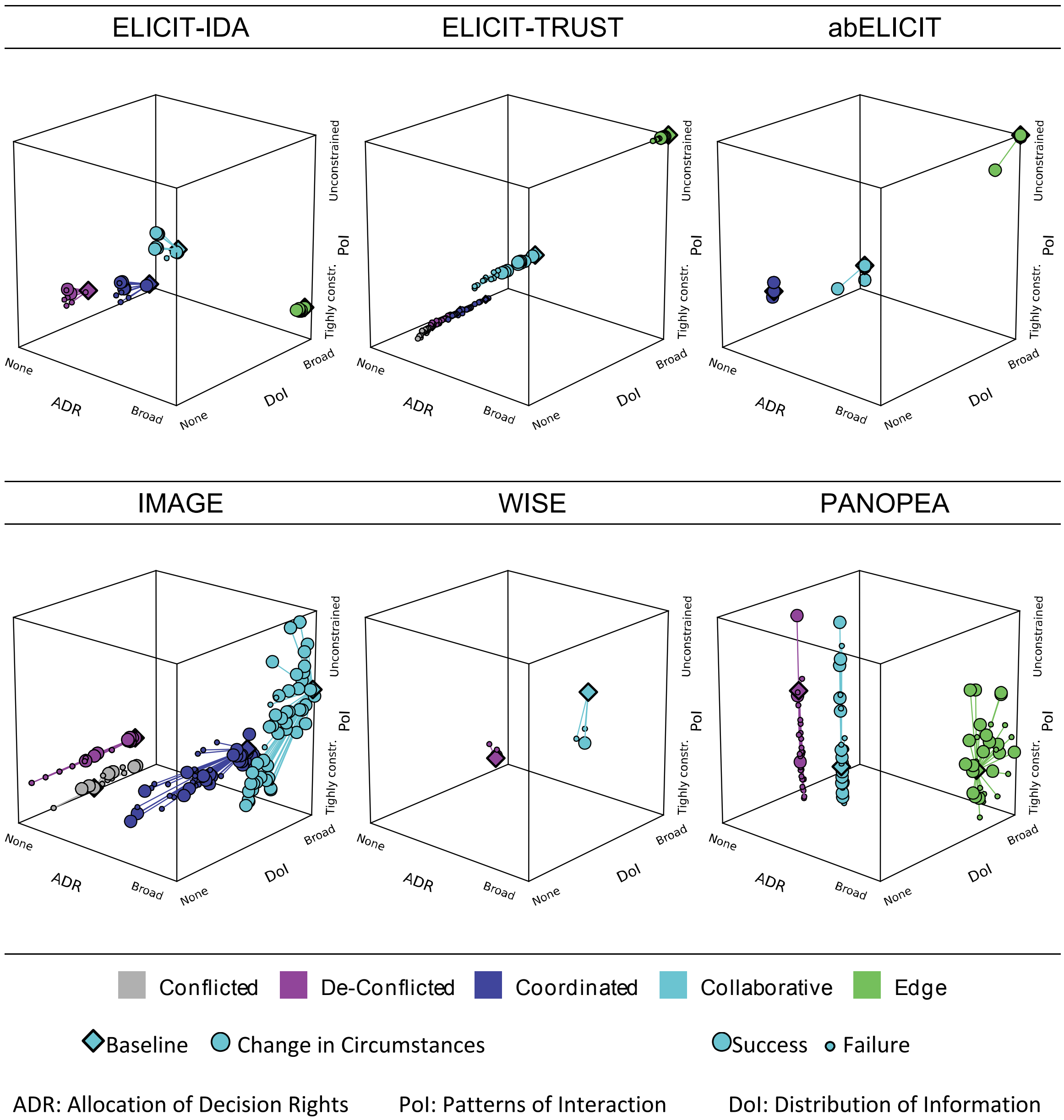


Figure 6.9: Positions in the C2 Approach Space

A mix between-within experiment analysis of variance was conducted to assess the potential of the C2 Approach Space to determine if the location of each C2 Approach is statistically distinguishable. The relationship between C2 Approach and position in the C2 Approach Space was modeled by a linear mixed model with a random *Experiment* effect in order to control for the unique aspects of each experiment. A

Bonferroni correction (0.05/3) was applied to correct for type I error due to multiple tests.

Figure 6.10: Average Positions in C2 Approach Space presents the resulting S-mean for each dimension and C2 Approach.

C2 Approach	ADR	PoI	DoI
Conflicted	-0.05 (0.13)	0.04 (0.07)	0.36 (0.12)
De-Conflicted	0.10 (0.12)	0.25 (0.06)	0.41 (0.11)
Coordinated	0.41 (0.12)	0.28 (0.06)	0.43 (0.11)
Collaborative	0.50 (0.12)	0.43 (0.06)	0.63 (0.11)
Edge	1.08 (0.12)	0.44 (0.06)	0.98 (0.12)

Figure 6.10: Average Positions in C2 Approach Space

There was a significant effect for C2 Approach for each of the dimensions of the C2 Approach Space, i.e. for ADR [$F(4,829) = 1284.00$, $p < .001$, $\eta^2 = .53$], PoI [$F(4,829) = 101.1$, $p < .001$, $\eta^2 = .12$], and DoI [$F(4,420) = 179.79$, $p < .001$, $\eta^2 = .42$]. Post hoc comparisons performed with Tukey's test reveal that all pairs of comparisons for all dimensions were significant except for three pairs in DoI (Conflicted vs. Coordinated, Conflicted vs. De-Conflicted, and De-Conflicted vs. Coordinated) and two pairs in PoI (De-Conflicted vs. Coordinated and Collaborative vs. Edge).

It follows from these results that although, 1) circumscribing each C2 Approach depends on how we measure them, 2) the unique aspects of the experiment influence the observed values, and 3) C2 Approaches overlap in terms of DoI and PoI, the differences in locations in the C2 Approach Space are statistically significant and therefore we can accept the hypothesis that each of the N2C2M2 C2 Approaches is located in a distinct region of the C2 Approach Space. An extension to this finding is that, except for the Edge C2 Approach, the C2 Approaches continue to be located in distinct regions of the C2 Approach Space in spite of adverse events or degraded conditions. In addition, and more importantly, Figure 8 shows that Edge and Collaborative are able to maintain their position in the C2 Approach Space (retain significantly higher values of ADR, PoI, and DoI simultaneously across all three dimensions) when compared to Coordinated, De-Conflicted and Conflicted.

Figure 6.11: Average Locations with .95 Confidence Limits shows the average locations in the DoI-ADR and the DoI-PoI planes. The positions correspond to LS-mean with the consequence that they can be outside the 0-1 range because of the extrapolation used for missing values. Error bars indicate 0.95 confidence intervals. Confidence regions were not computed but correspond to ellipses (or ellipsoids for the three dimensions).

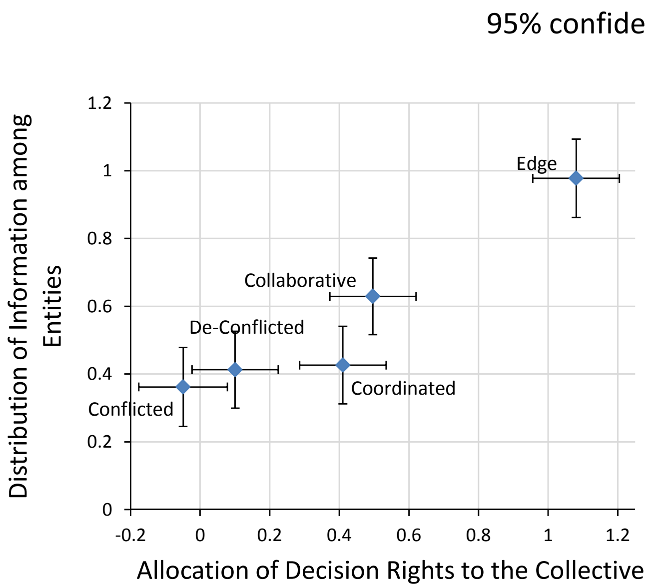


Figure 6.11: Average Locations with .95 Confidence Limits

Figure 6.12: Theoretical v. Calculated C2 Approach Positions maps each C2 Approach into a three-dimensional space (right) with colours and orientation similar to the theoretical model (left). Each ellipsoid is centered on the LS-means of each C2 Approach and its radius corresponds to the 0.95 confidence interval in each dimension. The first thing readers will notice is that the locations of the ellipsoids are shifted up and to the right when compared to the theoretical locations. This result is a combination of how DoI was measured in the experiments and the use of LS-means that involve extrapolation for missing values. Nevertheless, the relative

positions derived from the experimental data comply largely with the N2C2M2 theoretical model. It should also be noted that the locations of the C2 Approaches in the C2 Approach Space were roughly estimated by the SAS-065 NATO group and such estimations were never intended to be a definitive statement as to the location of each C2 Approach. The region or spread of each C2 Approach is smaller within the experimental model than the theoretical one, for the calculated regions represent confidence intervals and such intervals assume a normal distribution, which may not be entirely true in the real world. The range of values observed for the PoI dimension departs the most from the NATO NEC C2 Maturity Model. PoI was also the most difficult measure to establish during the experimental design. Discussions about the results in H6 identify the most likely explanations for this departure from the theoretical model.

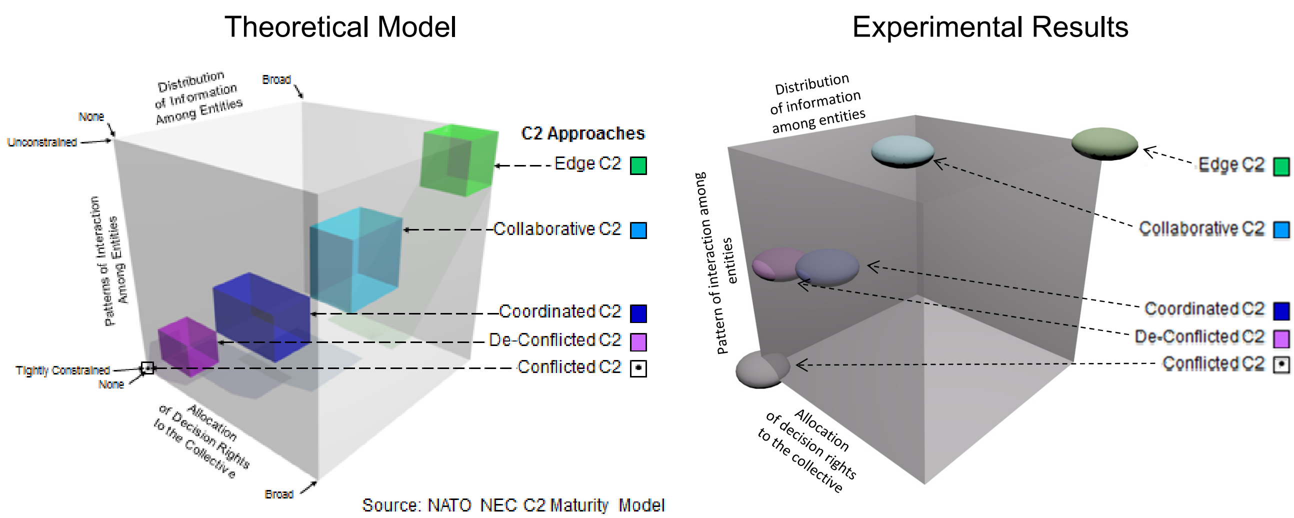


Figure 6.12: Theoretical v. Calculated C2 Approach Positions

One further observation is that the entire volume of the C2 Approach Space is not occupied. The reason for this is that the locations of the simulated C2 Approaches tend to follow a pattern that corresponds to a distribution along the diagonal. There is a better way (or at least more compact way) to orientate the dimensions of the C2 Approach Space such that the first dimension of this new space captures most of the variability (i.e., the first axis of this space would be aligned with the greater spreading of points), the second dimension would capture the second higher amount of variability, and so on. For this purpose, a principal component analysis was conducted on the location in the C2 Approach Space of each circumstance in order to identify the optimal transformation (rotation) and the amount of variance accounted for by each new dimension. Analysis indicates that the new referential is oriented according to the vector (0.589, 0.585, 0.558). The first dimension (of the new referential) accounts for 72.5% of the variability. The second dimension for 15.5% while the third dimension accounts for 12%. These results indicate that a C2 Approach "plane" would be sufficient to represent 88% of the C2 Approach Space. The results are similar when compared with the average location of each C2 Approach (vs. the results from each circumstance) for each experiment. The first dimension accounts for 81% of the variability, the second for 12%, and the last one for 8%.

In summary the results show that the N2C2M2 C2 Approaches are located in a distinct region of the C2 Approach Space and are robust in the face of adverse events or degraded conditions. The experimental model of the C2 Approach Space largely validates the N2C2M2 theoretical model, although there are some notable deviations that need to be studied further but may be a result of the how these approaches were instantiated and the metrics used to measure their locations in the approach space.

6.13.2 H2: No one C2 Approach to C2 is always the most appropriate

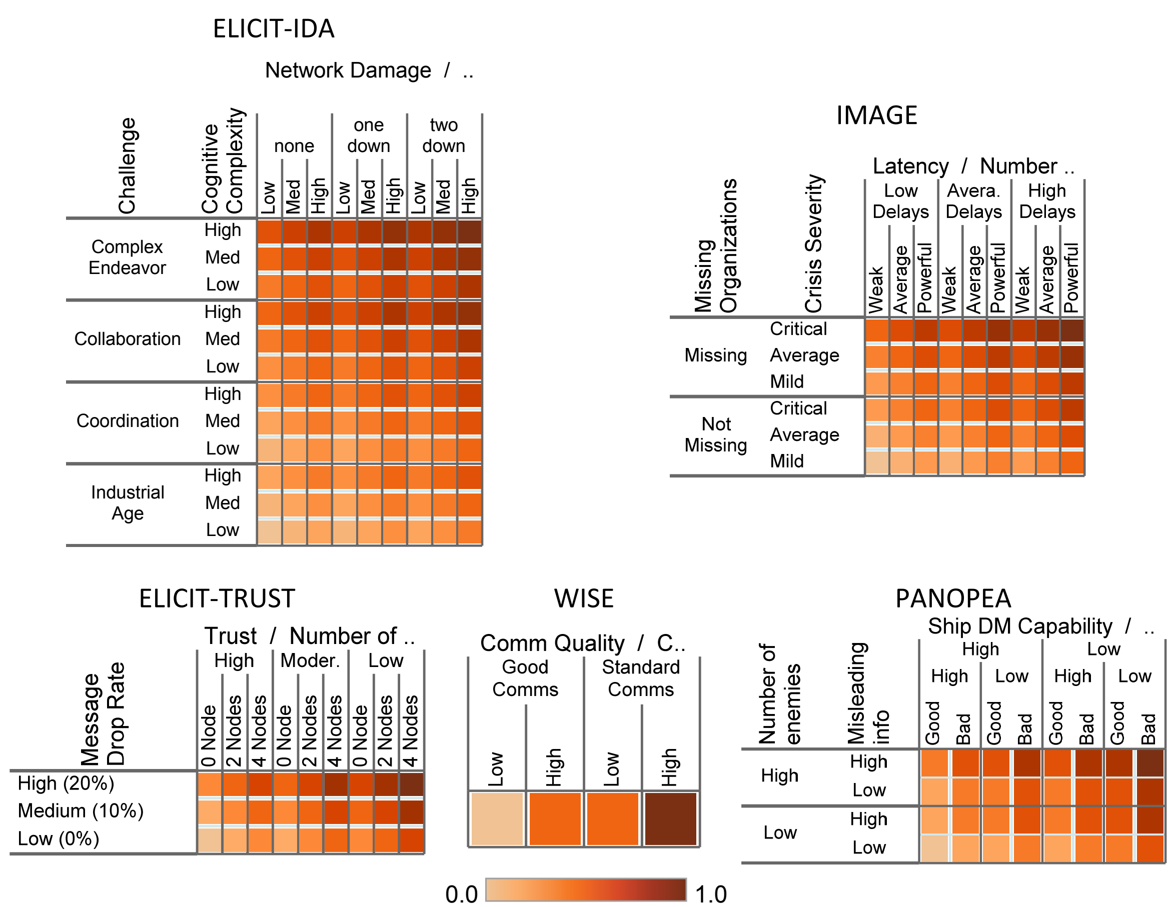
Even if Collectives have the C2 Maturity to be able to adopt more network-enabled C2 Approaches there are circumstances for which less network-enabled C2 Approaches are just as effective in ensuring success or indeed are the only approaches able to succeed. In addition, even when multiple C2 Approaches succeed in the same region of the Endeavour Space, choosing the most network-enabled ones is not always the best option. Cost and time constraints as well as the difficulty or practicality of applying more network-enabled C2 Approaches, e.g. Edge or Collaborative, in some situations may favour the adoption of less network-enabled C2 Approaches.

Thus, Entities that are able to adopt more than one C2 Approach should be successful in a greater portion of the Endeavour Space than Entities that can only adopt a single C2 Approach, even if it is the most agile of the C2 Approaches. C2 Manoeuvre Agility is defined by SAS-085 as the ability to appropriately adopt more than one C2 Approach. This involves understanding the circumstances one is in, knowing which among the C2 Approaches that can be adopted is the most appropriate, and if necessary transitioning from the current C2 Approach to this more appropriate approach, in a timely manner.

Since Agility is the capability to successfully cope with circumstances, it is always relative to a specific Endeavour Space. The dimensions of Endeavour Space capture the important variable characteristics of mission, environment, and Self. These variables can take on different values and a given set of these values constitutes a point or cell in Endeavour Space which experimentally was referred to as a circumstance. One way of visualising success or failure within regions (collections of point or cells) of Endeavour Space is through Agility Maps, which are graphical representations of the success or failure of a Collective employing one or more approaches to C2.

Since Endeavour Spaces can easily consist of more than two dimensions making them difficult to graphically portray, they have been translated into a plane. This was accomplished by assigning more than one variable to each of two dimensions (x and y axes) of the Endeavour Space, meaning that some variables are nested within others. In each of these experiments, C2 Approaches were instantiated under every possible combination of Endeavour Space variables. Thus, the resulting Agility Map comprises a cell for each unique circumstance. Given that there can only be one circumstance that exists at any point in time, any other combination of variable values constitutes another circumstance. The value obtained for the measure of success for each circumstance is one for a Collective employing a given C2 Approach. Each Endeavour Space was organized such that the less challenging mission/circumstances were placed closer to the bottom left-hand corner while the most challenging circumstances were closer to the top right-hand corner with a quantitative gradation of expected difficulty when moving from one corner to the other.

Figure 6.13: Endeavor Space Difficulty shows, for each experiment, a normalized value representing the expected degree of difficulty for each circumstance across samples of the Endeavour Spaces implemented[101]. Each level for each variable defining the Endeavour Space was assigned the smallest possible integer, with positive values corresponding to expected positive effects on mission and negative values with negative effects. For instance, for *Network Damage* in ELICIT-IDA, 1 was assigned to Low network damage, 0 to Medium network damage, and -1 to High network damage. In the case where variables had two levels, e.g. *Misleading Info*, only +1 (Low) and -1 (High) were assigned. Since each circumstance is the combination of all possible values of all variables, the degree of expected difficulty was calculated by summing the assigned values for each variable. The resulting numbers were normalized between zero and one, with one being the most challenging circumstance.



[101] The *Challenge* dimension of ELICIT-IDA was named similarly to C2 Approaches and should not be confused with their corresponding C2 Approaches.

Figure 6.13: Endeavor Space Difficulty

An easy way (but with limited benefits) of testing H2 consists in finding at least one circumstance for which the most successful C2 Approach is not the same as for the other circumstance (which is probably the most network-enabled one). As the Agility Maps presented in both Figures 6.14: Comparative Agility Maps with Most Network-Enabled as Tiebreaker and 6.15: Comparative Agility Maps with Least Network-Enabled as Tiebreaker show, no single C2 Approach dominates all others in every situation. The first approach chooses the C2 Approach from among those that satisfy conditions that is thought to be the most agile (see H4) while the second chooses the least costly. In both cases, these Figures show that more than one C2 Approach is selected to satisfy the demands of these Endeavor Spaces.

However, this way of testing H2 is limited in its generalization. The intrinsic variability in the experiments precluded the Experimentation Team from claiming that such findings apply to the whole population of experiments (and the real situations they represent), analogous to a making a claim that a drug is efficient with the entire population if it saved only one person's life. A proper statistical test had to be conducted by considering the possible variability of each experiment. A pessimistic and an optimistic method were used to conduct the analysis.

Figure 6.14 shows the results of the conditions simulated within each experiment corresponding to the pessimistic method; in cases where more than one C2 Approach was equally effective, the most network-enabled approach was selected. The results show that the most network-enabled C2 Approach is always the most appropriate across the sample of Endeavour Space for experiments conducted with WISE, PANOPEA, and IMAGE. As for ELICIT-TRUST and ELICIT-IDA, the most network-enabled C2 Approach was not the best C2 Approach across 6.5% and 18.5% of the Endeavour Space respectively. A single sample one-tailed t-test determined that the mean value (M = 5.0%, SD = 8.1%) was not significantly different from zero, $t(4) = 1.386$, $p = 0.119$. This result can be explained by the fact that IMAGE and PANOPEA calculate their mission success on a binary scale, making it impossible to perform comparisons among those that measure the success of C2 Approaches along a continuous scale. This success value for another C2 Approach is a minimum value considering the binary scale issue with IMAGE and PANOPEA, hence the term pessimistic.

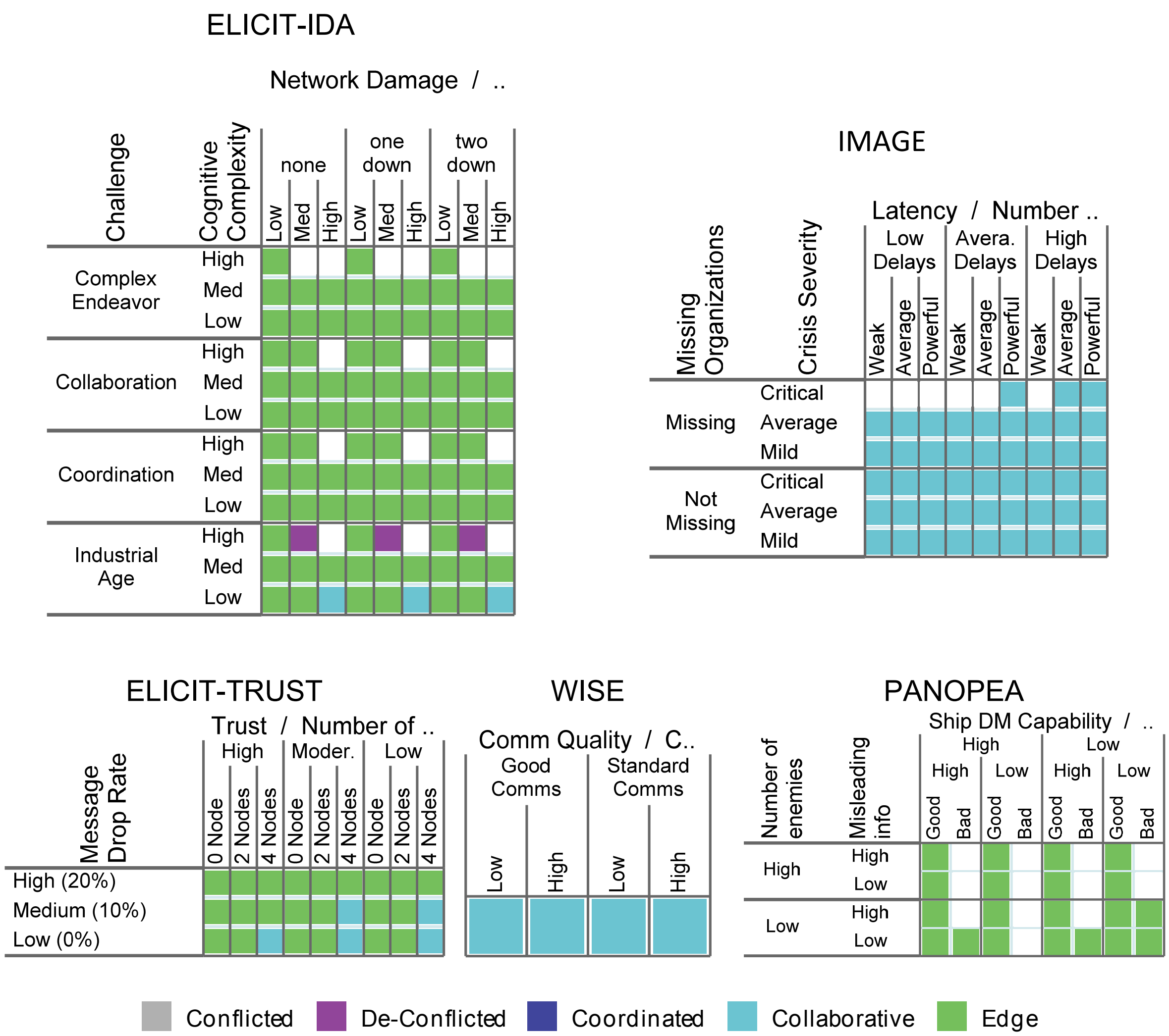


Figure 6.14: Comparative Agility Maps with Most Network-Enabled as Tiebreaker

Figure 6.15 shows the results for the optimistic method which selected the least network-enabled C2 Approach when more than one C2 Approach was equally effective. Although Collaborative and Edge approaches are better to cope with more challenging circumstances, other C2 Approaches are sufficient for many less, but still challenging, circumstances. The most network-enabled C2 Approach was not the best C2 Approach across 18.5% (ELICIT-IDA), 9.7% (ELICIT-TRUST), 66.7% (IMAGE), 0% (WISE) and 75.0% (PANOPEA) of the Endeavour Space. A single sample one-tailed t-test determined that the mean value (M = 35.3%, SD = 33.8%) was significantly different from zero, $t(4) = 2.339$, $p < 0.05$. Even if the pessimistic method is not significantly different from zero, the results of the second method are sufficient to support H2 that no one C2 Approach to C2 is always the most appropriate.

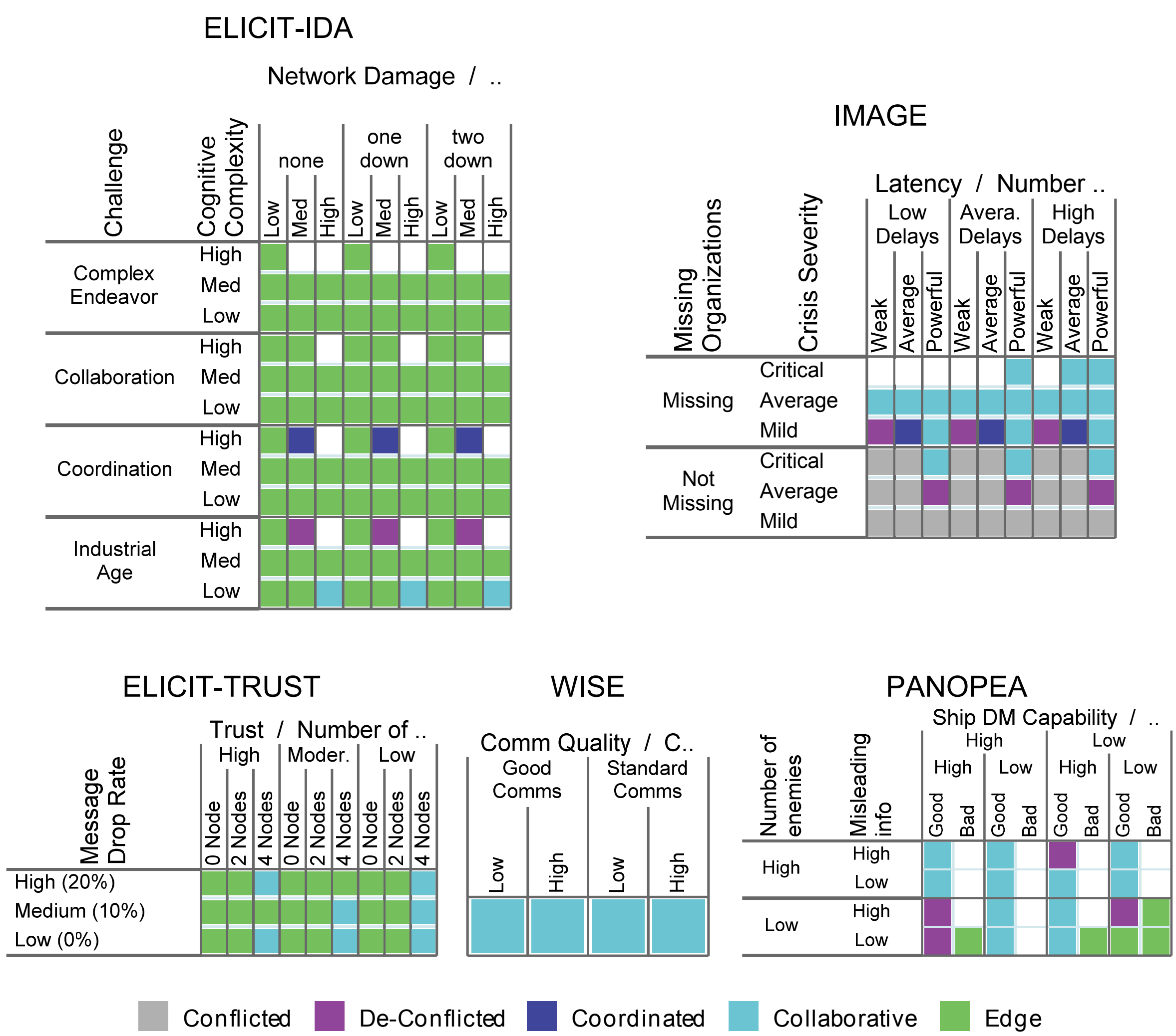


Figure 6.15: Comparative Agility Maps with Least Network-Enabled as Tiebreaker

6.13.3 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

While H2 considered if "no one size fits all", H3 considers if different contexts require specific C2 Approaches. The context in question here is the level of difficulty/challenge of a particular mission or set of circumstances. Visual inspection of Figure 6.14 clearly shows that the most network-enabled C2 Approaches succeed for the most challenging (top-right corner) circumstances. The inverse is also true, i.e. the least network-enabled C2 Approaches succeed for the least challenging (bottom-left corner) circumstances. It should be noted that this figure does not show if the second (or the third) best performing C2 Approach is as effective as the best one. A more detailed graphical representation would be needed to show the stacked squares (ones underneath the one shown) hidden in the figure.

In summary the meta-analysis shows that when considering H2 and H3 the most network-enabled C2 Approach was by far the most successful, being successful in the face of adverse events or degraded conditions and is consistent with the findings presented for H1. The experimental findings largely validate the N2C2M2 theoretical model that more network-enabled C2 Approaches are more successful in Complex Endeavours. However, there are clearly circumstances where more network-enabled approaches are inappropriate.

6.13.4 H4: More network-enabled approaches to C2 are more agile (possess more C2 Approach Agility)

An important objective of the meta-analysis was to assess the effect that adopting a C2 Approach has on an Entity's Agility, i.e. on the ability of the Collective to successfully cope with a relatively large portion of the Endeavour Space. In order to determine if more network-enabled approaches to C2 are more agile, the Experimentation Team devised a MoM that expressed the success of a Collective employing a particular C2 Approach given a particular set of circumstances in each experiment to calculate an Agility score.

Figure 6.16: C2 Approach Agility Maps presents the set of Agility Maps that corresponds to this experiment (one map for each C2 Approach). Values of success are binary in the case of IMAGE and PANOPEA (1=success, 0=failure) while they are continuous (between 0 and 1) for the other experiments. This is because either each measure of success represents the average of many replications or because the measure was simply continuous to begin with. The greater the success across portions of the Endeavour Space the darker the shades of teal while the lighter shade of teal represents failure in all portions of the Endeavour Space simulated in the experiments. Blank squares represent cases that were not simulated because the C2 Approach was not instantiated within the experiment.

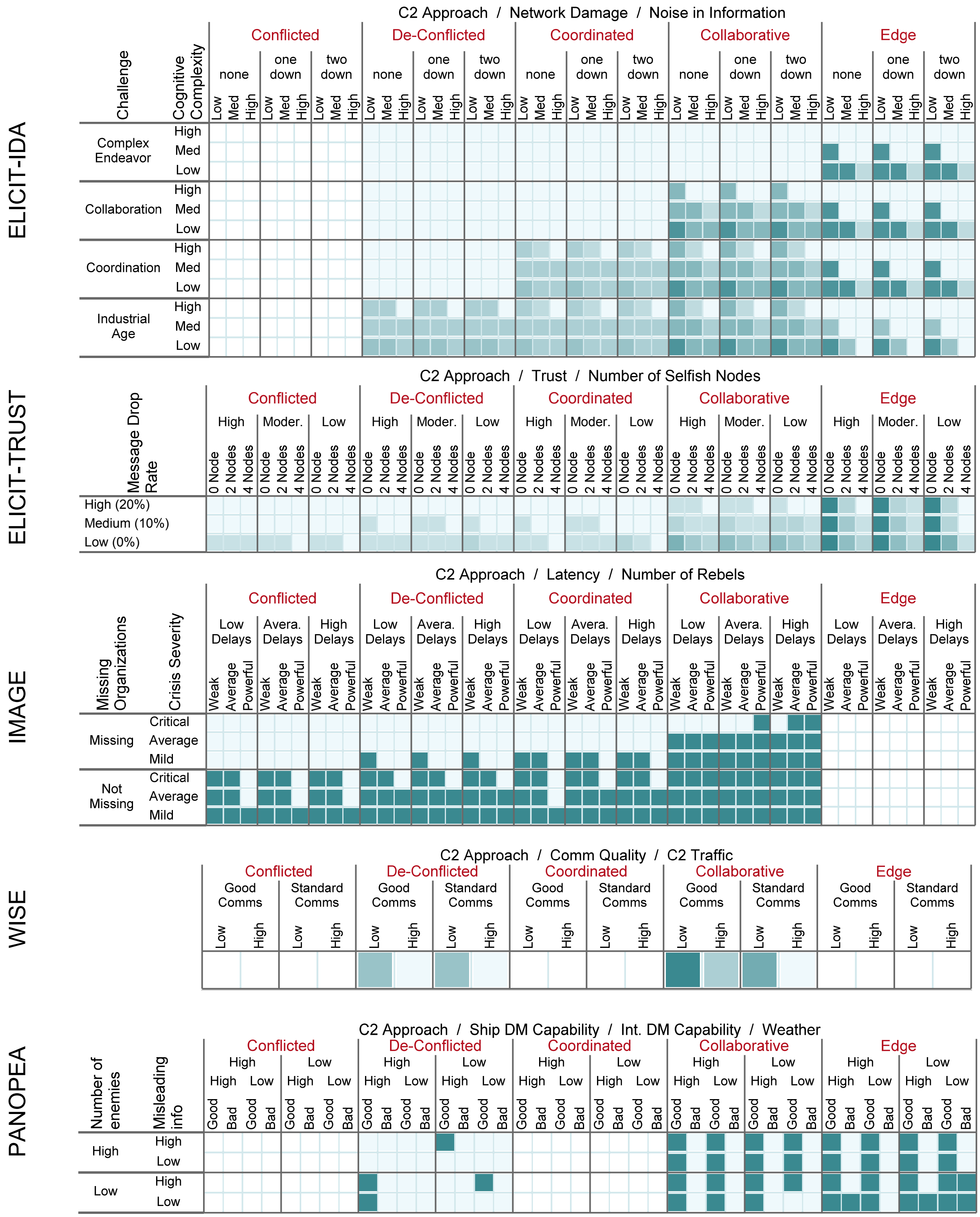


Figure 6.16: C2 Approach Agility Maps

Figure 6.17: C2 Approach Agility Scores shows the Agility score calculated for each C2 Approach for each experimental platform. The results are consistent. For every experimental platform, adopting a more network-enabled C2 Approach resulted in achieving a higher Agility score.

C2 Approach	ELICIT-IDA	ELICIT-TRUST	abELICIT	IMAGE	WISE	PANOPEA	LS-Mean
Conflicted		0.04		0.39			0.09 (0.10)
De-Conflicted	0.06	0.06		0.50	0.21	0.13	0.14 (0.09)
Coordinated	0.10	0.06	0.02	0.54			0.20 (0.09)
Collaborative	0.26	0.18	0.13	0.89	0.42	0.47	0.39 (0.09)
Edge	0.55	0.46	0.33			0.63	0.59 (0.09)

Insert Figure 6.17: C2 Approach Agility Scores

The meta-analysis conducted assessed the effect of C2 Approach on the Agility score using a linear mixed model with *C2 Approach* as a fixed effect and *Experiment* as a random effect in order to control for the variations in the specific scale for the Agility score across each experiment (effect of blocking as explained previously).

The results showed there was a significant effect [$F(4,11) = 30.68$, $p < .001$] for the C2 Approach, with an effect size $\eta^2 = .90$ [very large]. Post hoc comparisons performed with a Tukey's Honestly-Significant-Difference test revealed that seven out of 10 paired comparisons were significant (see Figure 6.18: Estimated Pairwise Changes in Agility Scores). The two most network-enabled C2 Approaches (Edge, Collaborative) demonstrated significantly more Agility than the two less network-enabled C2 Approaches (Coordinated, De-Conflicted) and the absence of a Collective C2 Approach (Conflicted) that is associat4ed with an absence of inter-entity networking. Small "increments" in capability for less network-enabled C2 Approaches (e.g. from De-Conflicted to Coordinated) were not sufficient to result in a significant improvement in Agility.

	De-Conflicted	Coordinated	Collaborative	Edge
Conflicted	0.05 (0.06)	0.11 (0.06)	0.30 (0.06)**	0.50 (0.06)***
De-Conflicted		0.05 (0.05)	0.25 (0.04)***	0.45 (0.05)***
Coordinated			0.19 (0.05)**	0.40 (0.05)***
Collaborative				0.20 (0.05)**
Note. *p <.05; **p<.01; *** p < .001				

Figure 6.18: Estimated Pairwise Changes in Agility Scores

The results of the meta-analysis strongly support H4 that more network-enabled approaches to C2 are more agile. In addition to testing for this specific hypothesis the meta-analysis also yielded an unexpected observation regarding Agility that has arisen as a direct result of the experiments undertaken. The resulting observation was not apparent during the theoretical development of the conceptual model of Agility nor was it evident during the conduct and analysis of the case studies but is worthy of further research. Figure 6.19: Average C2 Approach Agility Scores shows the progression of Agility scores as an organization moves from a given C2 Approach to a more network-enabled C2 Approach. Assuming that C2 Approaches are equally distant from each other on a “C2 Approach scale”, the relationship between C2 Approach and the Agility score is quadratic with a correlation coefficient of 0.99[102]. Such a result suggests that Agility benefits are non-linear and that Agility benefits accelerate with more network-enabled C2 Approaches.

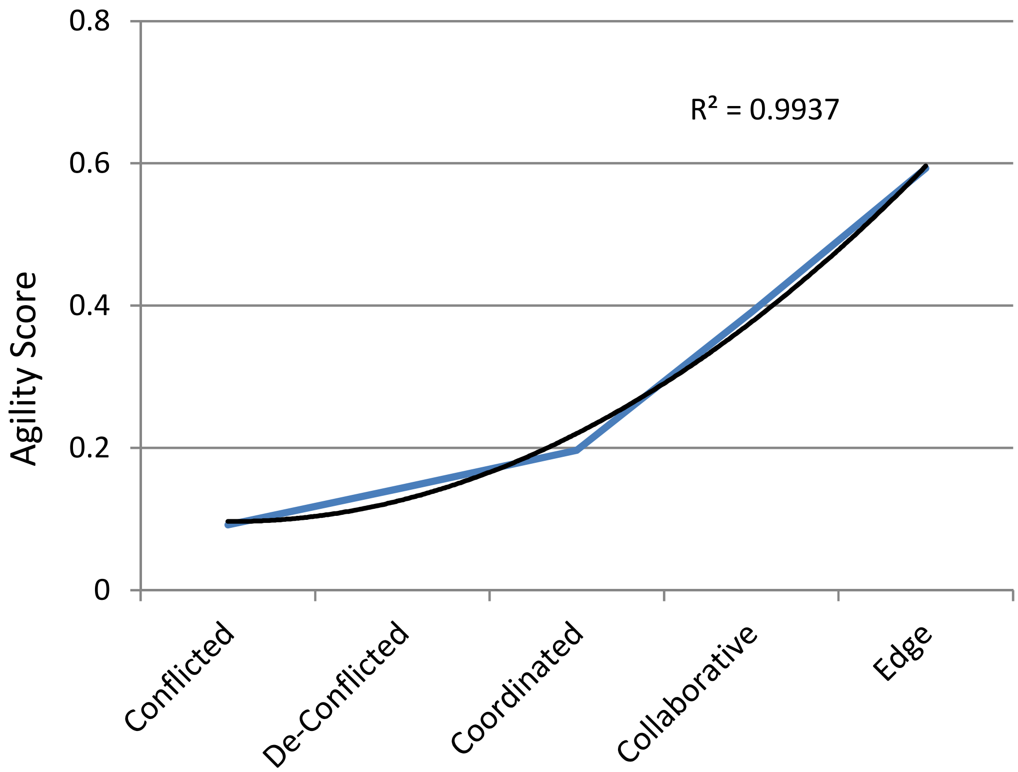


Figure 6.19 Average C2 Approach Agility Scores

One possible explanation for this quadratic relationship is that the C2 Approach Space is acting as a mediator variable[103]. Investigations identified that the most likely mediator variable was probably the distance of a C2 Approach from the origin in the C2 Approach Space. The distance from the origin of the C2 Approach Space to the LS-means position of each C2 Approach was calculated (see Figure 6.20: Average Distance from Approach Space Origin shows that this distance increases quadratically (R^2 = 0.987) when moving toward more network-enabled C2 Approaches.

[102] Although fitting five points with a quadratic equation that comprises three degrees of liberty will certainly result in high coefficient of correlation, 0.99 is still quite a high number even in this context.

[103] A mediator variable is a third explanatory variable (e.g. location in the C2 Approach Space) that explains the mechanism that underlies an observed relationship between an independent variable (e.g. C2 Approach) and a dependent variable (e.g. Agility Score).

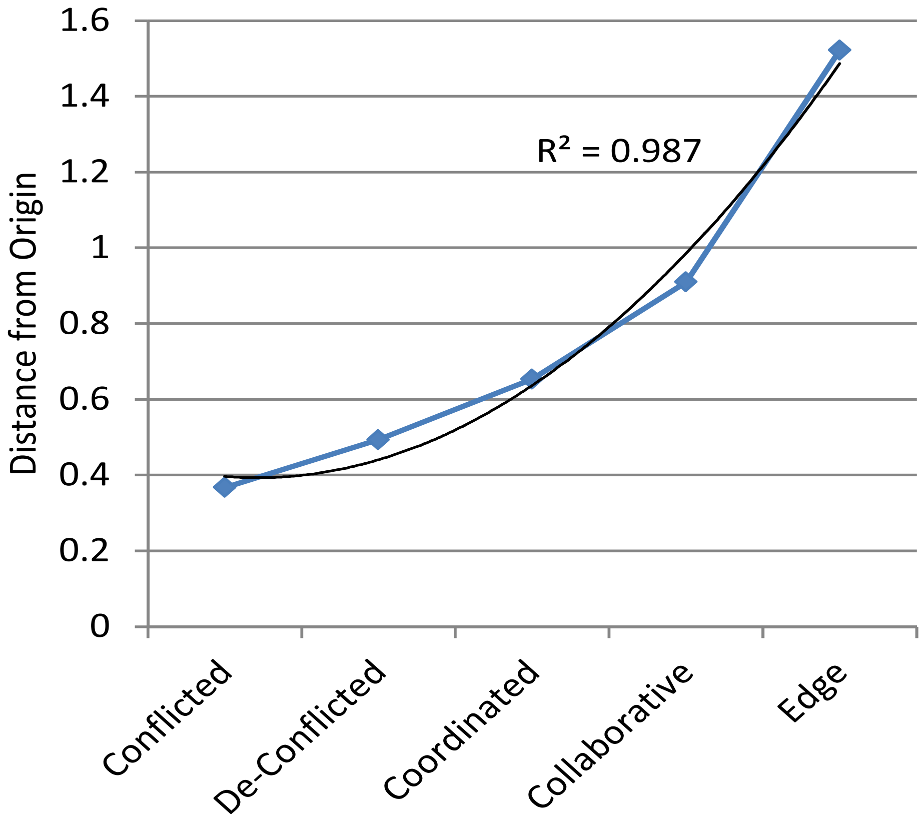


Figure 6.20: Average Distance from Approach Space Origin

Since both the measure of Agility and the average distance from the origin behave quadratically, one should not be surprised to observe a high level of linear correlation (R^2 = 0.989) between these two variables (see Figure 6.21: Distance from Origin and Agility Score).

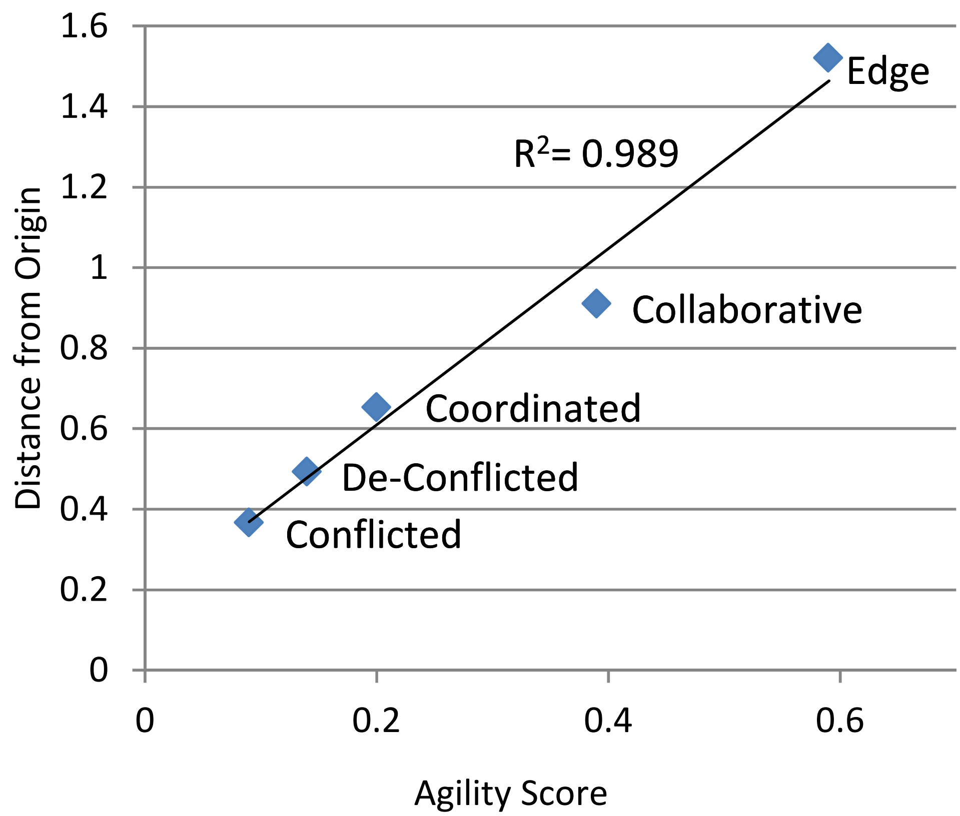


Figure 6.21: Distance from Origin and Agility Score

This finding should not preclude further discussion about the reasons for the observed quadratic effect and a search for a possible mediator variable. For instance, the distance from origin is based on the scales employed for ADR, PoI and DoI. The effect of these variables, both individually and collectively, on Agility is investigated in H5. An additional likely explanation is the hypothesized need for balance among the three C2 Approach dimensions in order for a C2 approach to be agile. H7 explores this possibility. Finally, other underlying variables not included in this analysis could be sources for this quadratic effect. Further investigation is required to find the underlying cause(s).

In summary, the meta-analysis shows that when considering H4 more network-enabled C2 Approaches are more agile in the face of adverse events or degraded conditions and is consistent with the findings for the previous hypotheses. The C2ACM is consistent with the N2C2M2 theoretical model that more network-enabled C2 Approaches are more successful in Complex Endeavours because of their inherent Agility. Of particular note is the finding that Agility benefits are quadratic with significant Agility benefits gained when moving from De-Conflicted or Coordinated C2 Approaches to a Collaborative C2 Approach and when moving from Collaborative C2 Approach to an Edge C2 Approach. Results suggest that this quadratic effect comes from the distance a C2 Approach is from the origin in the C2 Approach Space.

6.13.5 H5: The dimensions of the C2 Approach Space are positively correlated with Agility

H5 explores the relationship between the dimensions of the C2 Approach Space and the Agility score. The results of the meta-analysis in relation to H2 and H3 showed that Entities with broad ADR, unconstrained PoI and broad DoI are more successful. Thus, it would be expected, given that H4 showed that more network-enabled C2 Approaches are more agile, that the dimensions of the C2 Approach Space will be positively correlated with the Agility score.

Figure 6.22: Position in the Approach Space and C2 Approach Agility shows the average position of each C2 Approach in each dimension of the C2 Approach Space (estimated marginal means calculated from all experiments, hence the negative values). The coefficients of correlation between each dimension and Agility are $R^2 = 0.965$, $p < 0.01$, $R^2 = 0.858$, $p < 0.05$, and $R^2 = 0.983$, $p < 0.01$ for ADR, PoI and DoI respectively. Although these correlations are unambiguous, that is each of the dimensions of the C2 Approach Space is highly correlated to the Agility score, looking at these results alone may be misleading because the dimensions of the C2 Approach Space are known to be related to one another in practice and hence may be related to one another in these experiments.

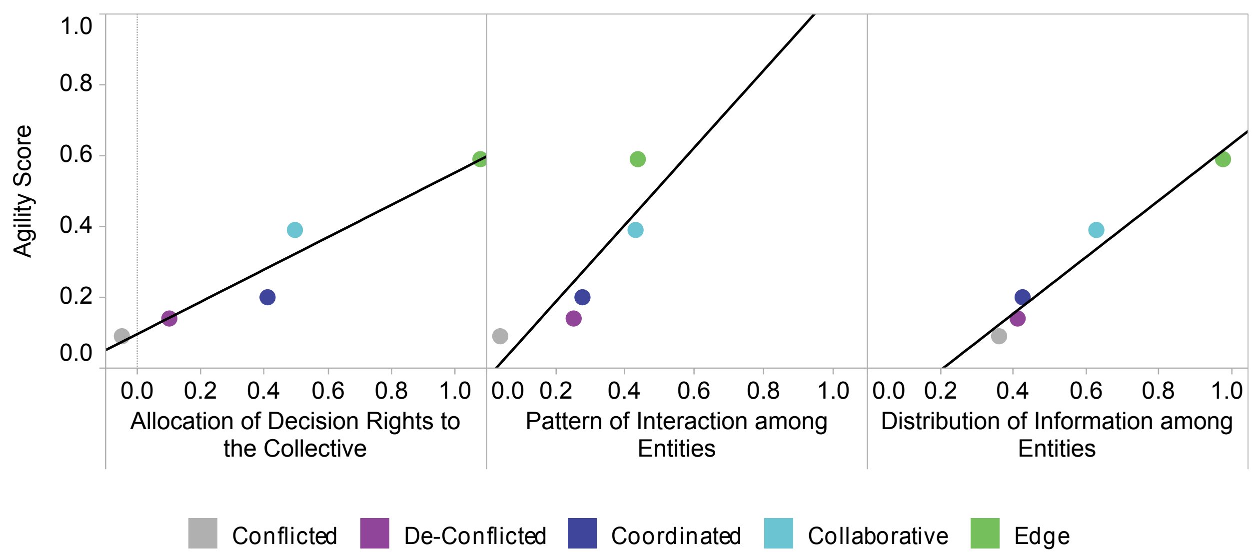


Figure 6.22: Position in the Approach Space and C2 Approach Agility

A more appropriate statistical approach was conducted using a multiple regression analysis based on the three predictors (ADR, PoI, DoI) in order to see if the average position in the C2 Approach Space significantly predicts (and is correlated with) the Agility score. Multiple regressions estimate the relationship between one or more potentially explanatory variables, or predictors, on one dependent variable. The contribution of each predictor is calculated while keeping the other predictors constant. The regression was calculated with 21 entries (the number of simulated C2 Approaches across all experiments). The result of this regression analysis indicates that the three predictors explain 51% of the variance (Adjusted $R^2 = 0.51$, $F(3,18) = 8.37$, $p = .001$), i.e. ADR, PoI, and DoI explain about half the variation in the Agility scores corresponding to each C2 Approach, confirming the potential of the C2 Approach Space to capture the conditions leading to Agility. Figure 6.23: Statistical Test Results for Dimensional Predictors of Agility summarizes the β, t-test and significance level for each predictor.

C2 Approach Space \ Dimension (Predictor)	β	t(14)	P*
ADR	0.460	2.75	0.01
PoI	-0.269	1.26	0.22
DoI	0.274	1.26	0.22
***note: p < 0.25 which is considered as valid in multiple regression analysis**			

Figure 6.23: Statistical Test Results for Dimensional Predictors of Agility

The regression equation (Eq. 1 below) predicts the Agility score given the location of an Entity in the C2 Approach Space. Caution is necessary to ensure that extreme combinations of value for the variables are not used as this may result in incorrect predictions of Agility. In addition, a regression does not guarantee that the predictors are the cause of Agility, with the exception of ADR which was independently controlled during the design of the experiment.

$$\textit{Agility Score} = 0.030 + 0.460\,\textit{ADR} - 0.269\,\textit{PoI} + 0.274\,\textit{DoI} \qquad \text{Eq. 1}$$

The results show that ADR is the strongest single dimensional predictor of Agility. DoI has a positive but weaker correlation with Agility and PoI has a negative correlation with Agility. This finding contradicts the strong positive correlation observed in Figure 20 and seems to contradict the N2C2M2 theory. However, there are many reasons for this seemingly contrary result. Firstly, DoI and PoI are correlated ($R^2 = 0.49$) and Figure 20 does not allow for the extraction of the individual contributions of DoI and ADR from PoI. Multiple regression analyses evaluate the individual effect of each variable while keeping other predictors constant. When other predictors are kept constant, PoI has a small negative impact. Secondly, and perhaps more importantly, the measures of PoI used for this analysis are relatively immature and represent the frequency of interaction between Entities within the Collective and not the quality of the interactions or the willingness to share. Finally, PoI seems to increase in frequency to accommodate degraded conditions which often leads to mission failure. For instance, when the network infrastructure is partially down, organizations increase their tendency to exchange information through other means of communication. Consequently, PoI is probably not a direct cause of Agility but instead it enables DoI and one needs only so much interaction beyond which point the interactions can create unnecessary delays and workload. The exact relationship between PoI and Agility is certainly a subject that needs to be explored in future research. Therefore, the development and selection of metrics for PoI that capture the quality of interactions and the willingness to interact are needed.

The results of the meta-analysis for H4 revealed that Agility increases according to a quadratic equation when moving toward more network-enabled C2 Approaches. The analysis also showed that the distance from the origin to the average location of a C2 Approach in the C2 Approach Space is non-linear (quadratic). Multiple regressions offer the opportunity to refine previous analysis by looking at the individual contribution of each dimension on Agility. A quadratic regression was conducted with each dimension of the C2 Approach Space to see if it was better able to predict the Agility score than the linear regression. The result of the regression indicates that ADR, PoI and DoI together explain 71% of the variance associated with the Agility Score (Adjusted $R^2 = 0.71$, $F(6,16) = 20.82$), which is higher than the 51% obtained for the linear regression. The increased variance could be explained by an increase in the number of degrees of freedom of the fitted curve (7 instead of 4), but is likely a result of a quadratic relationship between the location of a C2 Approach and its Agility.

In summary, the meta-analysis shows that only two of the three dimensions of the C2 Approach Space are positively correlated with Agility. In addition, Agility increases in the form of a quadratic equation as of function of the degree to which a C2 approach is network enabled. This is consistent with the findings for the previous hypotheses that more network-enabled C2 Approaches are more agile in the face of adverse events or degraded conditions. The C2ACM is consistent with the N2C2M2 theoretical model which asserts that more network-enabled C2 Approaches are more successful in Complex Endeavours due their inherent Agility, although there is a notable exception in that PoI as measured across these experiments is not positively correlated with Agility. The relationship between PoI, DoI and workload clearly needs to be explored further.

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

The meta-analysis for H5 showed that more network-enabled C2 Approaches are manifestly more agile. The strong correlation between the position in the C2 Approach Space and the resulting Agility is one possible explanation of this result. Another possible explanation could be that more network-enabled C2 Approaches are not as affected by circumstances, that is the actual locations in the C2 Approach Space are closer to their intended or, in theory, their ideal locations for more network-enabled C2 Approaches than they are for less network-enabled C2 Approaches.

As previously discussed, both PoI and DoI were affected by circumstances, e.g. a degraded network or increased workload. Consequently, a measure of how much movement was observed in PoI and DoI was calculated by the area occupied by all of the circumstances simulated (area covered in the DoI-PoI plane) for each C2 Approach across each experiment. A convex-hull was built for each set of circumstances based on Andrew's monotone chain algorithm (Andrew, 1979) that computes the smallest convex set that contains all of the points. Then the area of the resulting polygon was calculated.

Figure 6.24: C2 Approach Footprints shows the set of locations observed (corresponding to the set of circumstances) in the DoI-PoI plane and the resulting convex hull for each C2 Approach in each experiment. Although one might be tempted to claim that some C2 Approaches occupy a smaller region in the C2 Approach Space, this conclusion is not statistical valid as the observed results may be due to the random distribution of the points used to compute the average (because of the two random independent variables *Cirucmsmtance* and *Experiment* as previously explained) and the randomness in the selection of those independent variables (selection of the degraded conditions). The surface of the spread was calculated for each C2 Approach and experiment.

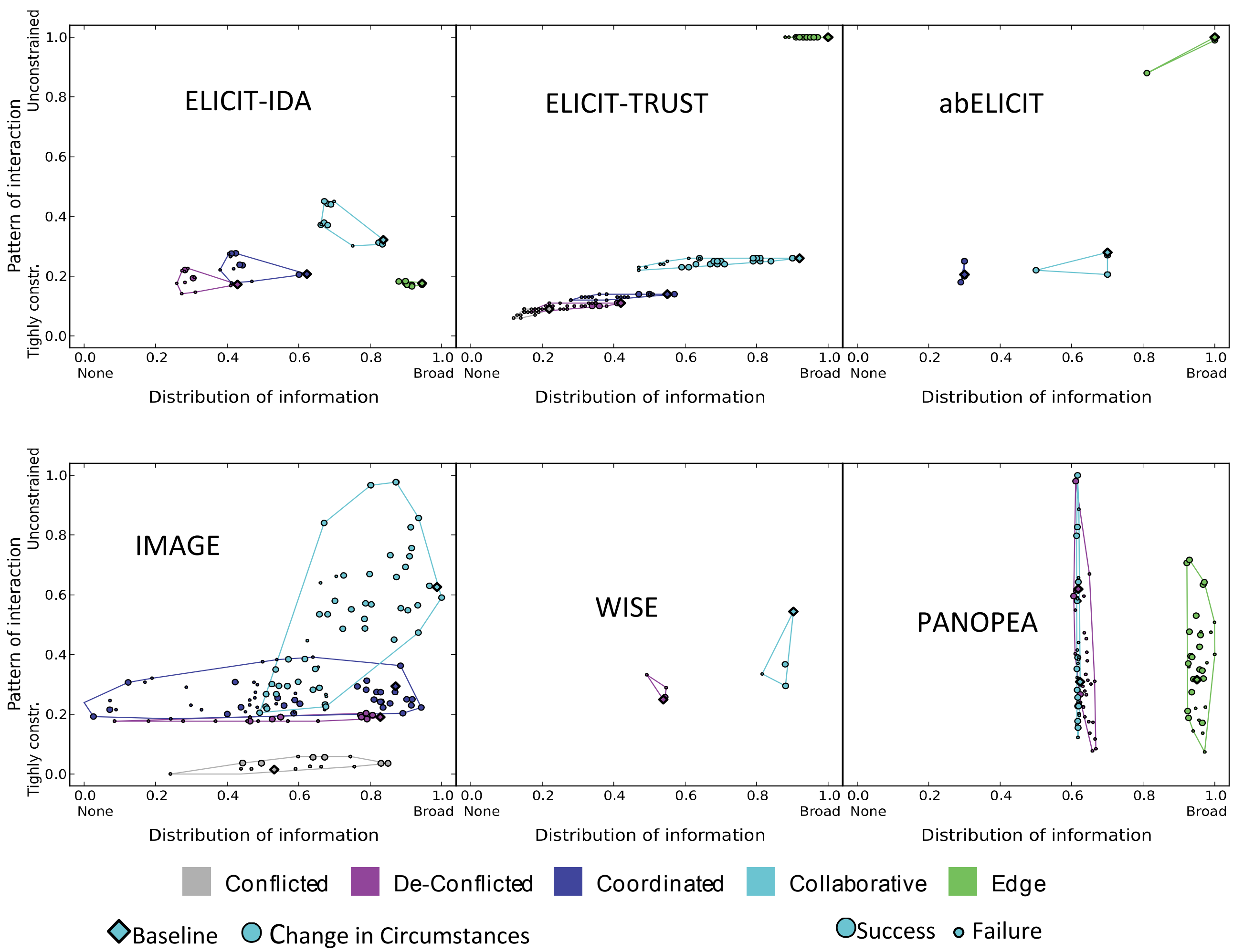


Figure 6.24: C2 Approach Footprints

A statistical test was conducted for the effect of C2 Approach on the area covered by all of the changes in circumstance in the DoI-PoI plane modeled by a linear mixed model with a random *Experiment* effect. There was no effect for C2 Approach on the calculated areas [F(4,11) = 0.81, p = .54]. However, visual inspection of the areas associated with C2 Approaches in ELICIT-IDA and ELICIT-TRUST show that in these experiments the positions in the C2 Approach Space for the most network enabled approach were less impacted by changes in circumstances than the positions of less network enabled approaches. Each of these experiments considered different endeavor spaces and these results may be related to the differences among these Endeavor Spaces.

C2 Approach \ Experiment	ELICIT-IDA	ELICIT-TRUST	abELICIT	IMAGE	WISE	PANOPEA	LS-Mean
Conflicted		0.002		0.018			-0.012
De-Conflicted	0.008	0.004		0.009	0.001	0.031	0.007
Coordinated	0.013	0.003	0.000	0.142			0.037
Collaborative	0.013	0.008	0.007	0.221	0.009	0.006	0.044
Edge	0.001	0.000	0.001			0.036	0.020

Average area covered in the PoI-DoI Plane.

Figure 6.25: Size of C2 Approach Footprints

The results of the meta-analysis do not support H6, although for some of the experiments the Edge is less subject to being moved away from its intended position than other C2 Approaches. This finding implies that the gain in Agility observed with more network-enabled C2 Approaches is a result of the average global location of the C2 Approaches and not their ability to maintain their positions. However, this result is probably due to the fact that each of these experiments did not implement all of the approaches and considered a different mix of stresses.

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

H7 explores the notion that there needs to be, among other things, a balance achieved among the three C2 Approach dimensions in order to be effective and hence agile. The N2C2M2 depiction of a set of C2 Approaches positioned along the diagonal of the C2 Approach Space graphically represents instances of approach co-evolution. Thus, these on-diagonal approaches represent approaches that are co-evolved to support operational concepts and are able to take advantage of the opportunities afforded by their network capability. For example, in terms of the C2 Approach Space, approaches along the diagonal possess PoI and DoI that efficiently support the ADR. That is, individuals are provided access to other individuals and the information they need to make the decisions for which they are responsible, in a timely manner. An off-diagonal approach would be one where the PoI or the DoI is either insufficient to support assigned decisions or while able to support required interactions and information flows, supports them inefficiently. Thus, this “diagonal hypothesis” would seem, on the face of it, to be obvious with no apparent reason why an Entity would choose to adopt an off-diagonal C2 Approach. To test this hypothesis a comparison was undertaken of the performance of a range of C2 Approaches, at different distances from the “diagonal”, comparing their Agility with respect to the Endeavour Space. The ELICIT-IDA experiment conducted such an analysis investigating positions along the diagonal, that is, C2 Approaches that are balanced with respect to the three axis of the C2 Approach Space, to determine if they were more effective than unbalanced C2 Approaches. To determine if the data from the ELICIT-IDA experiment supported the hypothesis, the runs were divided into two groups. The first group was formed by the runs that were equal to or less than a certain distance from the diagonal (.05), the on-diagonal group. The off-diagonal group consisted of the runs whose positions were observed to be greater than .05 from the diagonal. Figure 6.26: Off Diagonal Effectiveness shows the relationship between the average distance from the diagonal and the average percentage of the maximum effectiveness of these two groups. The on-diagonal group is, on average, more than twice as effective (see Figure 6.27: Distance from Diagonal v Maximum Effectiveness).

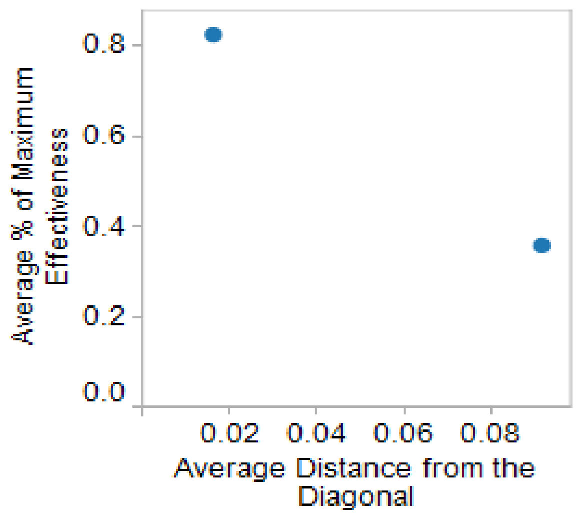


Figure 6.26: Off Diagonal Effectiveness

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

Figure 6.27: Distance from Diagonal v Maximum Effectiveness

The results of the analysis support H7 that on-diagonal (balanced) approaches to C2 are more agile that off-diagonal (un-balanced) C2 Approaches.

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

C2 Maneuver Agility involves navigating through the C2 Approach Space according to the situation. In order to do this appropriately a Collective needs to be able to detect when a change of C2 Approach is required and to make this change to the most effective C2 Approach (determined by the situation), in a timely manner in order to maintain success.

A realistic experiment would incorporate the imperfect processes that monitor the situation, detects (or anticipates) the point in Endeavour Space that represents the situation, selects the appropriate C2 Approach for this situation, models the transition between C2 Approaches (capturing the costs and time required), and calculates the possible negative operational impacts that may occur during this transition. While none of the experiments used in this meta-analysis included treatments examining the capability to transition from one approach to another, it is possible to calculate a value for Agility that approaches an upper bound by considering perfect C2 Maneuver Agility. This calculation involves selecting the best C2 Approach given each circumstance and is equivalent to setting the costs of transition and the delays involved to zero. The value obtained is close to the maximum Agility possible given the Endeavour Space and the set of C2 Approach options available but is not actually the maximum because the method does not include the benefit of anticipating changes in circumstances, i.e. it does not implement the proactive monitoring that exploits weak signals (Hollnagel, Woods, & Leveson, 2006) thereby announcing the early arrival of significant events in order to initiate a change before being fully impacted by a change in the situation (which is the case here.)

As explained previously, C2 Maturity Levels define the groups of C2 Approaches a Collective can adopt and therefore can choose from. Maturity Level 1 includes Conflicted while Maturity Level 2 includes De-Conflicted only. Each subsequent level (3-5) includes an additional C2 Approach, namely Coordinated, Collaborative, and Edge. The portions of the Endeavour Space where a Collective can be successful were calculated for each C2 Maturity Level across each experimental platform (see Figure 6.28: C2 Maturity and Agility). These values were calculated by selecting the highest success value among the C2 Approaches comprising a given maturity level. The results in Figures 6.28 and 6.29 for Maturity Level 1, corresponding to Conflicted, and Maturity Level 2, corresponding to De-Conflicted, differ from the results presented earlier. This was because abELICIT was excluded from the current analysis due to missing data. Assuming that Collectives with more mature C2 would be better at pre-emptive/early transitioning between C2 Approaches, the values computed here are probably an underestimate of the Agility scores for the higher levels of C2 Maturity.

Statistical tests were conducted in order to see if higher levels of C2 Maturity provide more Agility than the lower levels, i.e. Does increasing C2 Maturity improve the Agility of a Collective? As previously, the effect of C2 Approach on the Agility score was modelled by a linear mixed model with a random Experiment effect.

Agility Scores

C2 Maturity Level \ Experiment	ELICIT-IDA	ELICIT-TRUST	IMAGE	WISE	PANOPEA	LS-Mean
Level 1		0.04	0.39			0.07 (0.13)
Level 2	0.06	0.06	0.50	0.21	0.13	0.12 (0.11)
Level 3	0.10	0.07	0.56			0.21 (0.11)
Level 4	0.27	0.18	0.89	0.42	0.47	0.37 (0.11)
Level 5	0.61	0.48			0.63	0.52 (0.11)

Figure 6.28: C2 Maturity and Agility

The results of the meta-analysis showed that there was a significant effect [$F(4,8) = 11.19$, $p < .001$] for the level of maturity, with an effect size $\eta^2 = .86$ [very large]. Post hoc comparisons performed with a Tukey's Honestly-Significant-Difference test revealed that five out of the 10 paired comparisons were significant with both maturity level 4 and 5 resulting in significantly more Agility than maturity levels 1, 2 or 3. The results are similar to those obtained from analysis that compared the Agility scores corresponding to each of the C2 Approaches and raises the issue of whether the Agility of a given level of C2 Maturity comes from the ability to switch from one C2 Approach to another or simply from the fact that it can adopt a more network-enabled C2 Approach.

Figure 6.29: Marginal Gain of Maneuver shows the Agility scores corresponding to the union of all C2 Approaches included in a C2 Maturity Level and the most network-enabled C2 Approach it includes. At least in this set of experiments, the Agility associated with the different C2 Maturity Levels comes from the most Network enabled C2 approach they contain rather from their ability to adopt multiple approaches to C2.

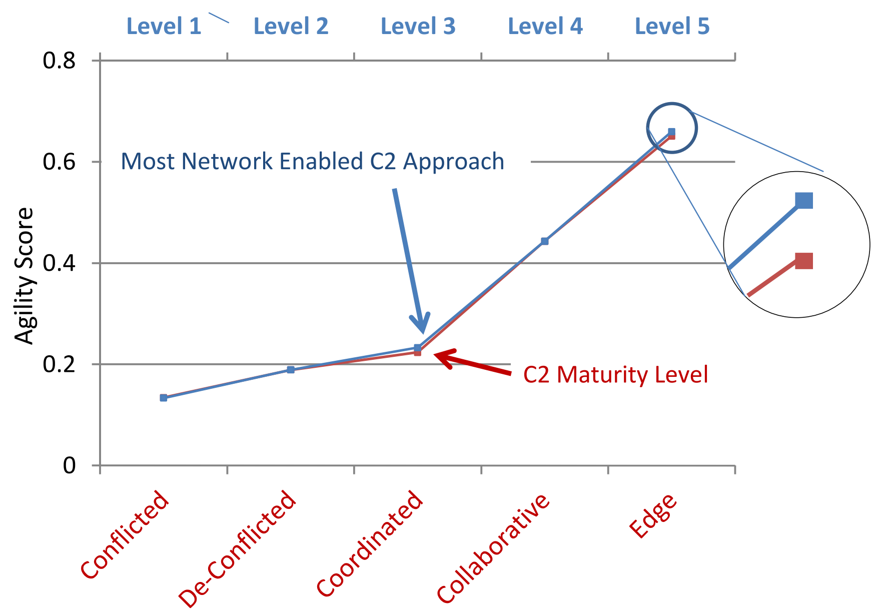


Figure 6.29: Marginal Gain of Maneuver

Figure 6.30: Marginal Gains from Adopting More Network Enabled C2 Approaches shows the computed difference between each C2 Maturity Level and the most network-enabled C2 Approach it includes.

Marginal Gains in Agility Scores

Level Most N-E C2 Approach \ Experiment	ELICIT-IDA	ELICIT-TRUST	IMAGE	WISE	PANOPEA	LS-Mean
Level 1 - Conflicted		0.000				0.000 (0.000)
Level 2 - De-Conflicted	0.000	0.000	0.000	0.000	0.000	0.000 (0.000)
Level 3 - Coordinated	0.006	0.007			0.006	0.011 (0.007)
Level 4 - Collaborative	0.003	0.000	0.000	0.000	0.003	0.001 (0.001)
Level 5 - Edge	0.014	0.010		0.000	0.014	0.008 (0.007)

Figure 6.30: Marginal Gains from Adopting More Network Enabled C2 Approaches

Although the differences are small, a paired samples t-test confirmed that the difference between Agility scores (M = .003) is statistically different from zero, t(17) = 2.44, p = .01. However, a difference of 0.3% across the Endeavour Space represents, on average, a small benefit. However, the differences between simply adopting the most network-enabled approach and being able to maneuver get larger as an Entity gets more mature. That is because the most network-enabled approaches may be most appropriate for complex and dynamic situations (supported by our findings with respect to H3 and H4) and are less well-suited for relatively simple and static situations. This is suggested by the case studies and by the Agility Maps from The Agility Advantage (Alberts 2011).

SAS-065 found that an Entity attaining higher levels of C2 Maturity is more agile. While this is entirely consistent with our results, the reason that C2 Maturity is related to agility could be a result of 1) the increased Maneuver Agility associated with increased maturity or 2) the ability to be more network-enabled that is also associated with increased maturity, or 3) both. When the effect of the increased ability to employ a more network enabled approaches is removed then we find a difference, one that is statistically significant. However this difference is relatively small and may not be significant in practice.

One explanation for the small average difference revealed by this last test is the incomplete/deficient selection of the circumstances populating the Endeavour Space across the experiments. Since many of the circumstances chosen in the experiments are variations of the same type of challenge, some effects may be exaggerated. For instance, Edge will almost certainly succeed against all less difficult versions of a particular circumstance (different levels of network damage) if it already succeeds against the most challenging one. Consequently, the Endeavour Space is populated mainly by quantitatively rather than by qualitatively different challenges, but the latter is where Agility manifests its benefits.

Future experiments should try to create as varied an Endeavour Space as possible, thus incorporating a more diverse set of circumstances. Another explanation is the unbalanced level of resources between the C2 Approaches in some experiments. More network-enabled C2 Approaches are more sophisticated (e.g. require more training) and involve more resources (e.g. costly infostructure). The analysis does not consider the costs of these investments. A more complete cost-benefit analysis would be required to see if the investments in more network-enabled C2 Approaches were cost-effective. Finally, it is reasonable to assume that a higher level of C2 Maturity should have been better at pre-emptive/early transitioning between C2 Approaches, an aspect not implemented in the current set of experiments.

In summary, the meta-analysis shows that there is some value-added by being able to adopt the variety of approaches provided by a level of maturity as opposed to adopting the most network enabled for all situations. This needs to be further explored in other experiments and case studies.

6.14 SUMMARY

This chapter covered the experimental validation of the SAS-085 conceptual model. The methodology, the experimental design, and the results for the hypotheses tested were presented. Figure 6.31: Findings of Campaign of Experiments summarizes the findings and shows that the experimental results support seven out of the eight hypotheses. The level of support/amount of evidence is indicated in the third column with more discussion provided in following chapter.

Hypothesis	Evidence Found	Amount
H1: Distant C2 Approaches	Yes	High
H2: No 'one-size'	Yes	Medium
H3: Network-enabled - Challenging	Yes	Medium
H4: Net-enabled - Agility	Yes	High
H5: Approach Space – Agility	Yes	Medium-high
H6: Network-enabled - Position	No	
H7: on v off diagonal C2 Approaches	Yes*	ELICIT-IDA only
H8: C2 Manoeuver - Agility	n/a	
H9: C2 Maturity - Agility	Yes	Low
H10: Self-monitoring - Agility	n/a	
H11: Components	n/a	
H12: Components - Agility	n/a	

Figure 6.31: C2 Hypothesis Findings: Experiments

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Chapter 7 - CASE STUDY FINDINGS

A case study involves a detailed analysis of historical situations where evidence is sought that may provide confirmatory evidence for various pre-conceived notions or hypotheses related to the concepts being explored. The advantage of case studies is that any conclusions drawn from the analysis pertain to real situations, thus case studies contribute to empirical validation. The disadvantage of case studies is that conclusions drawn for a case or set of cases may not be generalized to other situations. Since the sources for these retrospective case studies did not view the events with C2 Agility or the C2ACM in mind, there was a need to interpret the data using the concepts and terminology provided by the C2ACM and hence, a potential limitation of this approach. SAS-085 used case studies in a fashion similar to that used in SAS-065 (SAS-065, 2010).

7.1 CASE STUDY PLAN

As previously noted, these case studies serve four main purposes. First, they identify key concepts, enablers, constraints, and behaviours related to C2 Approach Agility and C2 Maneuver Agility, and verify their existence in real situations. A case study template was developed to guide case study analysis leaders as they looked for evidence for these concepts. Early in the process, the template was co-developed with C2 Agility concepts and terminology. For example, a quick look at a case study (Haiti) convinced us that many of the C2 Agility concepts that were being discussed (e.g. transitioning from one C2 Approach to another) could be found in a real situation Sometimes these quick looks at the case studies revealed new concepts, such as self-monitoring, that eventually found their way into the C2ACM. Needless to say, the concepts and case study SAS-085 sub-groups worked closely together throughout the process to ensure consistency of ideas and terminology. Thus, hypotheses were reformulated based upon insights from actual cases even while they were being tested. This is a reflection of the relatively immature state of the C2 Agility theory. By the end of the validation process, both the C2ACM and the approach to a case study had matured considerably.

The second purpose for the case studies was to help clarify the C2 Agility language and definitions (terminology). Clear terminology is necessary to effectively communicate the C2ACM. It is anticipated that the reader will benefit by careful, thoughtful, and thorough examination of the Agility terms.

Third, each case study provides an opportunity to demonstrate and assess the applicability of the C2ACM. Of necessity the model is abstract, which makes it challenging for most audiences to see and understand the model's implications for their 'real world' situations. Analogies are used to help make the model relevant, practical, clear, and easy for the reader to grasp.

Fourth, but no less important, case studies are used to validate the C2ACM. The validation analysis herein involves Face Validity where experts in C2 and Complex Endeavours agree on the model and its implications, Construct Validity where relevant variables and their relationships are logically developed within the model, and Empirical Validity where the variables and their relationships are identified and assessed for each case study. Empirical Validity is the focus of this case study chapter.

7.2 CASE STUDY METHODOLOGY

The case study methodology involved 1) proposing candidate case studies, 2) developing a case study template to guide data collection, 3) conducting case studies (Appendices A to I), 4) developing a generic "evidence table" so that results could be presented in a consistent fashion, and 5) performing an analysis across all cases searching for cross-cutting results as well as results that were unique to a given case.

Of particular interest to SAS-085 were case studies that involved Complex Endeavours that involved a number of organizational Entities or a Collective ('coalition of the willing') with problems to solve or situations to stabilize and that highlighted key aspects of the overall C2 Agility conceptual model. The cases selected by SAS-085 included transitions from major conflict to stability operations (e.g., Afghanistan and Iraq), internal military transformation (various nations), peace-keeping operations (Rwanda), cyber warfare (Estonia and Georgia), disaster relief (Garda and Haiti Earthquakes), major events (Munich and Vancouver Olympics), and complex battlespace (Helmand Province). These candidate case studies contain a wide variety of situations with changing levels of complexity and a group of organizations ready to tackle the problems.

SAS-085 members volunteered to lead one or more of the case studies. Figure 7.1: Case Studies by Event or Mission, provides a list of the case studies undertaken by SAS-085, grouped by type of event or mission: (see Appendices for details).

<u>Complex Battlespace</u>
Helmand Province
Comprehensive Approach in NATO Operations

<u>Peace-keeping and Personal Agility</u>
Rwanda Genocide 1994

<u>Cyber Warfare</u>
Estonia Cyber Attack 2007
Georgia

<u>Natural Disasters</u>
Garda Earthquake 2004
Haiti Earthquake 2010

<u>Major Events</u>
Munich Olympics 1972
Vancouver Olympics 2010

Figure 7.1: Case Studies by Event or Mission

The template developed by the SAS-085 case study group is shown in Figure 7.2: Case Study Template. It consists of ten main parts beginning with an executive summary (Part I.) Part II identifies the level of analysis, temporal phases, and other boundaries. Part III briefly summarizes the situation that would give indications about the appropriateness of a particular C2 Approach and the observed C2 Agility, if any. Part IV focuses on the consequences if an appropriate C2 Approach was not adopted or if C2 Agility were not manifested. Part V encapsulates high-level statements on whether C2 Approach Agility and C2 Maneuver Agility were manifested in the case. Parts VI and VII present the evidence found to support the Agility assessments. Part VII recounts any interesting vignettes from the case that might clearly illustrate C2 Approach Agility, C2 Maneuver Agility, or both. Parts IX, X, and XI provide the Assumptions, Conclusions, and Bibliography, respectively. The template was a living document and teams had to adapt it to their specific needs; but for the most part, this high level structure sufficed.

I. Executive Summary

II: Identify the Focus of and the Boundaries for the Case Study

III. Describe the Challenge or Opportunity that gave rise to the need for C2 Approach and C2 Manoeuver Agilities.

IV: What would have been the consequences of a failure to act in a way that demonstrates C2 Approach Agility and C2 Manoeuver Agility?

V: Was C2 Approach Agility and C2 Manoeuver Agility Manifested? If so, How?

VI: Which Enablers and Inhibitors of C2 Approach Agility were observable?

VII: What C2 Approaches were relevant (i.e., did different situation complexity levels require a corresponding different C2 Approach)? How can C2 Manoeuver Agility be inferred from what was reported or observed?

VIII: What interesting and important vignettes are included or can be derived from the case study to help create illustrative stories?

IX: Case Study Assumptions and Limitations:

XI: Bibliography

Figure 7.2 Case Study Template

7.3 GENERIC CASE STUDY EVIDENCE TABLE

Having a common template to guide those doing the different case studies helps to ensure that the data collected is comparable and hence provides an opportunity to conduct an analysis across case studies. The objectives for this analysis were to: 1) find evidence for C2 Agility in the form of C2 Approach or Maneuver Agility, thus validating, to some extent, the C2ACM, and 2) when manifested, determine the characteristics associated with C2 Approach Agility and C2 Maneuver Agility that were common amongst the cases being studied, as well as to highlight new and unique elements that may be used to refine the model. Definitions can be found in the ***Glossary*** for the terms used in the first column of entries in Figure 7.3: Generic Case Study Evidence Table with Illustrative Entries.

Concept/Component	Phase 1	Phase 2	Phase 3
C2 Maneuver Agility			
Endeavour Space Complexity	High	Medium	Low
Appropriate (Required) C2 Approach	Collaborative	Coordinated	De-conflicted
Actual C2 Approach	Between Collaborative and De-conflicted	Between Coordinated and De-conflicted	Closer to De-conflicted
Self-Monitoring	None	●	●
C2 Approach Space			
– Allocation of Decision Rights	Somewhat broad	Narrow	Narrow
– Distribution of Information	Broad	Broad	Not as Broad
– Patterns of Interaction	Constrained	Constrained	Constrained
C2 Approach Agility			
Flexibility	●		
Adaptiveness	●	●	
(Lack of) Responsiveness		High	
Versatility	●	●	
(Lack of) Innovativeness	●	●	Low
Resilience	Medium		

Insert Figure 7.3: Case Study Evidence Table with Illustrative Entries

All of the case studies were divided into temporal phases, indicated by the table columns. It was left up to case study analysts to decide how best to divide the case study into phases. Also, analysts had the option to enter into a table cell some indication of the existence of the concept (e.g., a check mark), a pre-determined categorical or nominal label (e.g., Conflicted) or an ordinal value (e.g., low) as applicable. There was sufficient latitude in completing the evidence table in recognition that the case study data sources are likely to have only indirect and interpretive evidence for many of the concepts, and so it is expected that definitive evidence will be rare for many of the concepts and enablers.

7.4 SUMMARY OF CASE STUDY FINDINGS

This section provides a very brief summary of each case study with the associated Evidence Table, followed by a few highlights of how the case study contributes to efforts to validate the C2ACM. Annex B presents detailed reports of each case.

7.4.1 Rwanda Genocide 1994

The case study begins on the 5th of October 1993 with the establishment of the UN Assistance Mission for Rwanda (UNAMIR) by the Security Council with Brigadier General Dallaire as the Force Commander of the military component. It ends on the 19 July 1994, by the Rwanda Patriotic Force (RPF) victory that ended the genocide by the Hutu extremists. The UNAMIR can be broken into four major phases: Phase 1 - UN Assistance Mission, Phase 2 - Violence Escalation, Phase 3 - Rwanda Monitoring Mission, and Phase 4 - Security and Protection of Refugees and Civilians.

The Phase 1 UN Assistance mission was intended to help implement the Arusha Peace Agreement signed by the Rwandese parties on 4 August 1993. That is, UNAMIR's mandate (Security Council Resolution, 872) was to assist in ensuring the security of the capital city of Kigali; monitor the ceasefire agreement, including establishment of an expanded demilitarized zone and demobilization procedures; monitor the security situation during the final period of the transitional Government's mandate leading up to elections; assist with mine-clearance; and assist in the coordination of humanitarian assistance activities in conjunction with relief operations. This involved 2,548 military personnel, including 2,217 formed troops and 331 military observers, and 60 civilian police; supported by international and locally recruited civilian staff.

On April 6, 1994, the president of Rwanda was killed when his plane was shot down. This event set off a 100-day “tidal wave of violence”. This corresponds to Phase 2. While the massacres happened, several foreign powers sent military intervention forces to extract their own nationals from Rwanda.

Phase 3 was a Rwanda Monitoring Role only. On April 21, 1994, the UN Security Council voted unanimously to withdraw most of the UNAMIR troops, cutting UNAMIR back to 270 troops. The mandate of UNAMIR was adjusted by Security Council resolution 912 (1994) of 21 April 1994, so that it could act as an intermediary between the warring Rwandese parties in an attempt to secure their agreement to a ceasefire; assist in the resumption of humanitarian relief operations to the extent feasible; and monitor developments in Rwanda, including the safety and security of civilians who sought refuge with UNAMIR. As the slaughter continued, UN peacekeeping forces stood by since they were forbidden to intervene, as this would have been inconsistent with their “monitoring mandate”.

Phase 4 involved the Security and Protection of Refugees and Civilians. After the situation in Rwanda deteriorated further, UNAMIR's mandate was expanded by Security Council resolution 918 (1994) of 17 May 1994, to enable it to contribute to the security and protection of refugees and civilians at risk, through means including the establishment and maintenance of secure humanitarian areas, and the provision of security for relief operations to the degree possible. Disputes over costs delayed the troops’ deployment. UNAMIR II was authorized in May, 1994 but only a tenth of the authorized troop strength was made available by UN member states as late as July 1994. On June 22, 1994, the U.N. Security Council authorized France to deploy 2500 troops (Operation Turquoise) to Rwanda as an interim peacekeeping force, with a two-month U.N. mandate.

The war ended on July 18, 1994, “The RPF took control of a country ravaged by war and genocide. On 19 July, the RPF succeeded in occupying the whole of Rwanda except for the zone controlled by the French. The RPF victory ended the genocide by the Hutu extremists.

The Rwanda case study examined the Agility between organizations that worked together toward resolving the tensions and genocide in Rwanda: that is, C2 Maneuver Agility and C2 Approach Agility within Self as well as within the Collective.

One analyst collected more than 20 information sources related to the Rwanda case study. From these sources, 10 have been selected for further analysis based on the different perspective they brought to the UNAMIR mission. The selected documents were written by United Nations, Human Rights Watch, Independent analysts as well as the commander of the mission (see Annex B for full list). The analysis included a qualitative assessment of the concepts and enablers listed in Figure 7.3. For example, the Allocation of Decision Rights scale introduced in (Alberts and al. 2010) was used as a guide for the assessment. The scale extends from a) the identification of not explicit or self-allocated decision rights (emergent, tailored and dynamic), to b) a collaborative process and shared plan, to c) a coordination process and linked plans, to, d) establishment of constraints, to, e) None (no allocation across the collective). Other examples of scales for the concept are found in Annex B.

Figure 7.4: Rwanda UNAMIR HQ – UN DPKO Evidence Table summarizes the evidence related to the relationship between the UNAMIR headquarters and the UN Department of Peacekeeping Operations (DPKO), and shows that the Endeavour Space Complexity moved from medium to high. The source documents provided no indication for the Required C2 Approach. The Actual C2 Approach was Collaborative for the most part, except for Phase 2 where it was reported to be Collaborative and then moved to Edge. Self-monitoring was performed continuously, and the organizations recognized the need to change approaches in Phase 2. Note that, very little evidence was found in the source documents for the Agility enablers.

Component/Concept	Phase 1	Phase 2	Phase 3	Phase 4
C2 Maneuver Agility		●		
Endeavour Space Complexity	Medium	High	High	High
Appropriate (Required) C2 Approach				
Actual C2 Approach	Collaborative	Collaborative / Edge	Collaborative	Collaborative
Self-Monitoring	Was done continuously	Recognized the need to change C2 Approach	Was done continuously	Was done continuously
C2 Approach Space				
– Allocation of Decision Rights	Limited	Limited / broad	Limited	Limited
– Distribution of Information	Broad	Broad	Broad	Broad
– Patterns of Interaction	As required	As required – significant broad	As required	As required
C2 Approach Agility				
Flexibility		Evidence Found		
Adaptiveness		Evidence Found		
Responsiveness		Evidence Found		
Versatility				
Innovativeness				
Resilience				

Figure 7.4: Rwanda UNAMIR HQ – UN DPKO Evidence Table

Figure 7.5: Rwanda UNAMIR HQ – Media Evidence Table summarizes the evidence found within the Collective for the relationship between UNAMIR and the media. The Endeavour Space Complexity moved from medium to high. Once again the source documents provided no indication for the Required C2 Approach. Over the phases, the Actual C2 Approach clearly transitioned from Conflicted to Coordinated. In contrast to the UNAMIR HQ – UN DPKO interaction where both Entities came under the UN umbrella and Self-monitoring was likely embedded in the organization, there were no initial obligations for the UNAMIR HQ – media interaction to have a Self-monitoring executive function, initially. However, by Phase 2, the organizations recognized the need to change approaches regarding how they worked with each other. There was evidence for Flexibility and Innovativeness, after Phase 1.

Component/Concept	Phase 1	Phase 2	Phase 3	Phase 4
C2 Maneuver Agility		●		
Endeavour Space Complexity	Medium	High	High	High
Appropriate (Required) C2 Approach				
Actual C2 Approach	Conflicted	Conflicted / Coordinated	Coordinated	Coordinated
Self-Monitoring	Continuous	Continuous/Recognized the need to change approaches	Continuous	Continuous
C2 Approach Space				
– Allocation of Decision Rights	None	Emergent	Emergent	Emergent
– Distribution of Information	Limited	All Relevant Information	All Relevant Information	All Relevant Information
– Patterns of Interaction	Limited, Sharply Focused	As Required	As Required	As Required
C2 Approach Agility				
Flexibility		Evidence Found	Evidence Found	Evidence Found
Adaptiveness				
Responsiveness				
Versatility				
Innovativeness		Evidence Found	Evidence Found	Evidence Found
Resilience				

Figure 7.5: Rwanda UNAMIR HQ – Media Evidence Table

7.4.2 Estonia Cyber Attack 2007

In 2007, the Estonia government decided to relocate a Soviet-era WWII memorial from a central location in the capital city to a military cemetery. However this decision was met by intense opposition from the Russian government and media. There were street riots and a siege of the Estonian embassy in Moscow conducted by Nashi (a Russian political youth movement) that included physical harassment of the Ambassador.

It is speculated that a Russian Cyber Attack against Estonia was an opportunity to project Russian power over the Estonians. This would be a broader message to countries in and around Estonia who recently joined NATO perhaps warning them of the consequences if they became affiliated with NATO. Russian authorities have denied any involvement.

This type and form of attack was something that the Estonians had never experienced and had no procedure for dealing with; at the time of the attack the Estonians had no national Cyber Security Strategy, but did create one the following year in 2008. The Estonians needed to be agile, but lacked Shared Situational Awareness (SSA) and a Cyber Common Operating Picture (COP) to help them analyze and respond to the challenge. The SSA and Cyber COP was created almost on the fly in a dynamic exploratory manner involving national and international organizations, such as the Computer Emergency Response Team for Estonia (CERT-EE), Ministry of Defense (MoD), NATO and national and international Information Technology experts. The Estonians experienced different types of attack including psychological, physical and Cyber.

The Endeavour Space complexity was high initially, but less so towards the end of the campaign from both the defender and attack perspectives, as indicated in Figure 7.6: Estonia Cyber Attack 2007 – Defender Perspective Evidence Table and Figure 7.7: Estonia Cyber Attack 2007 Attacker Perspective Evidence Table.

Concept/Enabler	Phase 1	Phase 2 (Wave 1)	Phase 2 (Wave 2)
Defender Perspective (Estonia)			
C2 Maneuver Agility			
Endeavour Space Complexity	High	High	Medium - High
Appropriate (Required) C2 Approach CYBER only	Collaborative	Collaborative	Collaborative
Actual C2 Approach CYBER only	Coordinated	Collaborative	Collaborative
Appropriate (Required) C2 Approach WIDER conflict	Coordinated	Coordinated	Coordinated
Actual C2 Approach WIDER conflict	De-conflicted	De-conflicted	De-conflicted
Self-Monitoring	None	Began to understand effect of defensive actions	Began to establish future capabilities based on learning
C2 Approach Space			
– Allocation of Decision Rights	Wide	Wide	Wide
– Distribution of Information	Broad	Broad	Broad
– Patterns of Interaction	Unconstrained	Unconstrained	Unconstrained
C2 Approach Agility			
Flexibility	High	High	High
Adaptability	Low	Medium	Low
Responsiveness	High	High	High
Versatility	High	High	High
Innovativeness	Low	Medium	Low
Resilience	High	High	High

Figure 7.6: Estonia Cyber Attack – Defender Perspective 2007 Evidence Table

Concept/Enabler	Phase 1	Phase 2 Wave 1	Phase 2 Wave 2
Attacker Perspective			
C2 Maneuver Agility			
Endeavour Space Complexity	High	High	Medium - High
Appropriate (Required) C2 Approach CYBER only	Coordinated + Edge	Coordinated + Edge	Coordinated + Edge
Actual C2 Approach CYBER only	Edge	Coordinated + Edge	Coordinated + Edge
Appropriate (Required) C2 Approach WIDER conflict	Coordinated	Coordinated	Coordinated
Actual C2 Approach WIDER conflict	Coordinated	Coordinated	Coordinated
Self-Monitoring	None	None	None
C2 Approach Space			
– Allocation of Decision Rights	Wide	Wide	Wide
– Distribution of Information	Broad	Broad	Broad
– Patterns of Interaction	Unconstrained	Unconstrained	Unconstrained
C2 Approach Agility			
Flexibility	Medium	Low	Low
Adaptability	Medium	Medium	Low
Responsiveness	Low	Low	Low
Versatility	Low	Low	Low
Innovativeness	Medium	Medium	Low
Resilience	Low	Low	Low

Figure 7.7: Estonia Cyber Attack – Attacker Perspective 2007 Evidence Table

The C2 Approach is tracked for both the cyber portion of the operation as well as the wider conflict. For the cyber portion, the required C2 Approach was Coordinated or Collaborative while the actual C2 Approach reached Collaborative, thus leaning towards evidence for C2 Maneuver Agility according to its definition. On the other hand, the wider conflict required Co-ordinated C2 but only achieved between Conflicted and De-conflicted C2, thus suggesting a lack of C2 Maneuver Agility. Self-monitoring was used to establish future capabilities. Evidence (presence or lack thereof) was found for all the Agility enablers. Note that ordinal values are given for *Lack of Responsiveness* and *Lack of Innovativeness*.

7.4.3 Georgia Cyber Attack

The cyber-attack on Georgia[104] in August 2008 is significant as the first example of a cyber-attack and military action being co-ordinated. In November 2009, Georgian National Security Council chief Eka Tkeshelashvili stated that (Shachtman, 2009) “Russia invaded Georgia on four fronts. Three of them were conventional — on the ground, through the air, and by sea. The fourth was new — their attacks via cyberspace… It is, quite simply, implausible that the parallel attacks by land and by cyberspace were a coincidence — official denials by Moscow notwithstanding."

South Ossetia is a territory about 60 miles to the North-West of the Tblisi (capital of Georgia); following the collapse of the Soviet Union, S. Ossetia claimed independence from Georgia, but this was not accepted by the international community. Following the Georgian War (1992-93) S. Ossetia broke away and became, de facto, an independent republic. The majority of the S. Ossetian population is ethnically distinct from Georgians, with their own language and an affinity with Russians. Tensions remained high in the region and a peace-keeping force of Ossetians, Russians and Georgians was established. On 7th August 2008, Georgia launched a surprise attack against S. Ossetian separatist to which Russia responded on 8th August. A five-day war followed in which Russian armed forces effectively drove Georgian forces from S. Ossetia; the conclusion was an agreement that prevented Georgia from taking military action in S. Ossetia in the future. An independent European Union report (EU, 2009) concluded that that Georgian attack that initiated the war was not justified by international law.

The cyber-attacks involved multiple botnets and ping flood scripts, and digitally doctored images appearing on the Georgian Foreign Ministry website. The US Cyber Consequences Unit concluded (US-CCU, 2009) that the cyber-attacks were carried out by civilians with little or no direct involvement on the part of the Russian military or Government; There was clearly advanced notice of Russian military intentions provided to the cyber attackers; the efforts of the attackers were supported by Russian organized crime. Of particular note is that there were so-called “dress rehearsal” attacks up to three weeks before the conflict and that a Georgian Hacker forum – that could have provided countermeasures – was attacked and neutralized (Hollis, 2011).

[104]

Concept/Enabler	Russian Cyber Militia	Russian Military	Russian Power Agencies	Russian Collective	Georgian Cyber Experts	Georgian Military	Georgian Civil	Georgian Collective
C2 Maneuver Agility								
Endeavour Space Complexity				High				High
Appropriate (Required) C2 Approach								
Actual C2 Approach	Edge	Between co-ordinated and conflicted	Mainly collaborative to de-conflicted	Between co-ordinated and conflicted	Edge	Between collaborative and de-conflicted	Mainly co-ordinated to de-conflicted	Between collaborative and de-conflicted
Self-Monitoring				●				
C2 Approach Space								
– Allocation of Decision Rights	Broad			Narrow				Narrow
– Distribution of Information	Broad			Between narrow and broad				Between narrow and broad
– Patterns of Interaction	Un-constrained	Constrained		Unconstrained				Between constrained and unconstrained
C2 Approach Agility								
Flexibility				High				High
Adaptiveness								High
Responsiveness								High
Versatility								
Innovativeness				High				
Resilience								

Figure 7.8: Georgia Cyber Attack Evidence Table

From the case study (see Figure 7.8: Georgia Cyber Attack Evidence Table), it has been deduced that at the overall conflict level, the Russian C2 was co-ordinated, but that this relied on Edge C2 being effective within the cyber aspect. By contrast, the Georgian C2 was deconflicted at the overall conflict level, with military and cyber actions being managed separately. However, within the cyber aspects, the C2 could be described as collaborative. In fact, Estonian CERT[105] officials were called in almost immediately and friendly servers and news stations outside Georgia temporarily hosted information as a part of the response to the cyber-attacks.

In contrast to Estonia, the number of Georgian internet users in 2008 was very small (7% of population) (CCDCOE, Nov 2008), nevertheless, the denial of service attacks proved very effective as a tactical disruption of Georgian communication channels. The attacks, which were co-ordinated with physical attacks, prevented the Georgian Government from informing its own population and the international community of what was taking place. Although there was no long-term impact of the cyber-attacks, their occurrence during short, but critical periods was a key enabler of the traditional military operations of the Russians (Hollis, 2011). In this sense, the Russians displayed a high degree of C2 Maneuver Agility.

[105] Computer Emergency Response Team

Overall the Georgians displayed *adaptability* and *responsiveness* as enablers of C2 agility, but the Russians displayed *innovativeness, responsiveness, flexibility* and *adaptability*. The opportunity for Georgian C2 agility was in co-ordination between cyber and military action, but this did not take place.

Although there are many similarities between the cyber-attack in Estonia in 2007 and the attack in Georgia in 2008, these are mainly in the technical aspects of the attack. The IT demographics in which the attacks took place were substantially different and the preparation and co-ordination of the attacks in Georgia were much more sophisticated. In the Estonian case study there were two main phases, with co-ordination only beginning in the second phase, whereas the Georgian case study appears to have a single and co-ordinated attack phase. Learning from the Estonian attack was clearly a factor, though, in the Georgian response in which rapid delegation of authority and information to the team of international cyber volunteers, and the movement of servers to alternate sites using personal relationships.

7.4.4 Garda Earthquake 2004

Garda Lake Earthquake took place 24 November, 2004, with epicenter in the town of Saló in the province of Brescia, Italy. The Collective for this case study is the Italian Civil Protection, which was developed as a 'modular force' model known among members as the 'Brescia Model' between 2000 and 2009. This Collective brought together virtually every organization that would respond to a civil emergency including individual citizens and voluntary groups. The notion of "Double Identity" was one of the strongest concepts driving the model: that is, everyone (bankers, students, housewives, etc.) could, and was encouraged to be a member of Civil Protection. There was a strong sense of duty, identity, and belonging that created the basis for collaboration and cohesion. Also, the diversity of citizens provided the collective with a broad and rich pool of competences and skills. All members of the Civil Protection took part in local exercises arranged every two-three weeks, as well as in regional exercises every quarter and a large national exercise yearly. A key tenet of the Brescia model was 'Being a System': that is, civil protection members and the population belong to the same system and are connected. Because of this tenet, the Province conducted a massive information campaign aimed at increasing the level of *awareness* of all possible threats (earthquakes, avalanches, terrorist attacks, etc.) and *responsibility* of each citizen in combating the threats. The Province also developed contingency plans as broad orientation to identify, e.g., where to set up a first aid tent, and so forth.

This case study could be divided into the following three phases:

- Phase 1: Emergency
- Phase 2: Stabilization
- Phase 3: Reconstruction

The Emergency phase took place immediately after the earthquake and was completed within the first twenty-four hours. During this phase *self-activation* and *self-coordination* of first responders was identified. Phase 1 gradually shifted into Phase 2 and 3. Stabilization and Reconstruction were carried out almost in parallel. As soon as the earthquake hit, all Civil Protection parties (Police, Armed Forces, Paramedics, Fire Fighters, Engineers, Volunteers, and so forth) activated automatically and self-coordinated. Nine hours after the earthquake, a unified operational room called "Mixed Operations Center" was opened in a high school, and had a coordination function with representatives from all parties. Each representative had direct contact with its people in the field. The reconstruction phase was completed by November 2005, and all people had returned to their homes.

Although the documentation of this case study does not explicitly report on the Required C2 Approach, Self-monitoring, and a few of the C2 Approach Agility enablers, it is clear that the Actual C2 Approach corresponds to Endeavour Space Complexity. (See Figure 7.9: Garda Earthquake 2004 Evidence Table).

Concept/Component	Phase 1: Emergency	Phases 2 & 3: Stabilization & Reconstruction
C2 Maneuver Agility		
Endeavour Space Complexity	High	Medium to low
Appropriate (Required) C2 Approach		
Actual C2 Approach	Edge	Collaborative to more Coordinated
Self-Monitoring		
C2 Approach Space		
– Allocation of Decision Rights	Broad moving to less Broad	More centralized
– Distribution of Information	Broad moving to less Broad	More structured
– Patterns of Interaction	Unconstrained moving to more formal interactions	More regular and less intense
C2 Approach Agility		
Flexibility		
Adaptiveness		●
Responsiveness	●	
Versatility	●	
Innovativeness		●
Resilience	●	●

Figure 7.9: Garda Earthquake 2004 Evidence Table

Data were gathered according to the principles of inductive qualitative research[106] from historical sources, reports, diaries, and interviews, and were aimed at establishing as much factual information as possible about the events. Further interviews were conducted to deepen and refine knowledge to address the case study template. Furthermore, the case study yielded other concepts not covered by the C2ACM.

This case study supports the expectation that Edge C2 would be an appropriate response to high complex situations and a Collective would move gradually down the diagonal of the C2 Approach Space as the complexity subsides. There is clear evidence that the Collective was prepared well in advance for this event.

[106] See Silverman, D. (2011) Interpreting Qualitative Data. SAGE Publications Ltd. 4th and Yin, R.K. (2008) Case Study Research: Design and Methods. SAGE Publications Inc. 4th

7.4.5 Haiti Earthquake 2010

An earthquake of magnitude 7.0 struck Haiti, just outside of Port-au-Prince, at approximately 1750 hrs on 12 January 2010. The devastation was wide-spread and especially acute in the densely populated areas surrounding the capital. Much of the critical infrastructure, particularly government and healthcare, was destroyed, drastically reducing the capacity of the Haitian people to recover without outside support. Prior to the earthquake, Haiti had already been receiving international humanitarian support through the United Nation Stabilization Mission in Haiti (MINUSTAH), but even this Entity was very seriously affected by the disaster. Several senior officials were killed, and the Mission was unfit to operate for some time. This set the stage for what was to be one of the most comprehensive international relief efforts ever. The United Nations dispatched a Disaster and Assessment Coordination team, which began arriving that day. The UN also adapted its Cluster System for application to the Haiti response and initially organized five clusters: Logistics, Shelter, Water and Sanitation, Health, and Food.

Within 48 hours of the initial event, the United Nations Stabilization Mission in Haiti also began to rebound from the initial shock of the earthquake and set up an emergency humanitarian coordination center at the Toussaint L'Overature International Airport and began clearing the main roads in Port-au-Prince in order to aid in the Search and Rescue effort. By the end of the second day, as many as twenty-one search and rescue teams were on the ground in Haiti.

The United States Air Force continued to provide emergency assistance in coordinating incoming flights to Port-au-Prince by assigning slot-times to planes wanting to offload in Haiti. In an effort to aid collaboration among the many actors involved in the response effort, the United States Defense Information Systems Agency opened its information portal, the All Partners Access Network, to any organization that was supporting the effort in Haiti.

Concept/Enabler	Phase 1: Search & Rescue Jan 13 – 22, 2010	Phase 2: Disaster Relief Jan 17 – Feb 1	Phases 3: Stabilization & Transition Feb 2 – March
C2 Maneuver Agility			
Endeavour Space Complexity	High	High to Medium	Medium to low
Appropriate (Required) C2 Approach			
Actual C2 Approach	Conflicted to De-conflicted	De-conflicted	Coordinated
Self-Monitoring			
C2 Approach Space			
– Allocation of Decision Rights	Narrow	Narrow	Less narrow
– Distribution of Information	No distribution	Narrow	Less narrow
– Patterns of Interaction	Less Constrained	Less Constrained	Somewhat Unconstrained
C2 Approach Agility			
Flexibility	High		
Adaptiveness	High		
Responsiveness	High		
Versatility	Medium		
Innovativeness	High		
Resilience			

Figure 7.10: Haiti Earthquake 2010 Evidence Table

Figure 7.10: Haiti Earthquake 2010 Evidence Table documents the evidence gathered for the C2 Maneuver Agility and C2 Approach Agility concepts. As with previous case studies, this case study was completed before Table 3 was fully developed, thus information about the Required C2 Approach and Self-Monitoring was not sought out. Upon close examination one might conclude that there is a discrepancy between the Actual C2 Approach in Phase 1 that indicates Conflicted to De-conflicted, and the C2 Approach Agility enablers, whose values would indicate an Edge-like Approach. However, these values are not for the entire Collective, but very specific pieces of evidence that the enabler did manifest itself sometime during the mission (see Annex B for specific examples).

7.4.6 Munich Olympics 1972

The Munich 1972 Olympics were promoted as the “Happy Games” twenty-seven years after WWII. This was an opportunity for Germany to showcase a completely different image of its new progressive society. Security personnel wore bright colored uniforms and carried no fire arms. It was to be the best Olympic Games the world had ever seen. However, terrorists took the opportunity to make a statement on the world stage. Unsuccessful rescue attempts led to the death of nine hostages and one police officer.

The Collective changed over time as organizations moved in and out of it over the course of the operation. At different points in time the Collective included Federal, State, and Municipal German Governments, National Army, Border Guard, Munich Police, International Olympic Committee, Organizing Committee, Israeli Government, Arab League, and key individuals from Egypt and Tunisia.

The case study was divided into five phases. Phase 1 was a pre-disturbance phase where there were assessments of potential threats, lessons learned from previous Olympics, management of ‘smaller’ disturbances, and security at the Olympic Village. Evidence for the C2ACM concepts and enablers are found for this phase as well as the others. The disturbance itself is divided into three phases. Phase 2 was the Hostages in the Apartment where the terrorists attacked the Israeli Team Headquarters, the Collective tries to negotiate with terrorists while Israel upholds their policy not to negotiate with terrorists, two rescue attempts fail, Germany declines support from Israeli’s Special Forces but Israeli experts join Crisis Team, and the Olympics are suspended. Phase 3 was moving the Hostages from the Apartment to Airfield where the ambush attempt failed but the terrorists were identified. Phase 4 was the Airfield Take-Down when a final ambush attempt was aborted resulting in an open gun fire fight. Phase 5, Post-Disturbance, involved changes to Government policy towards terrorists, creation of a counter-terrorism unit, and changes to internal security.

Three analysts collected Munich source data and became quite familiar with the event as well as C2ACM. They developed three data collection templates entitled, with a number of columns. As analysts read through the source data, they would fill out column 1 with the Concept they just came across, column 2 with the Source or Reference, and column 3 with a direct quote of the “evidence” for the concept listed in column 1. The fourth column indicated the “Strength (Score)” of the evidence (3 = direct quote of keywords in Concept definition, 2 = direct quote of related words, and 1 = inferred quote). The fifth column provided the inferred value for the Concept (e.g., medium). Column 5 was filled out independently, and then the analysts came together to examine the values, and come to consensus on a single value.

Concept/Component	Phase 1: Pre-terrorist attack	Phase 2: Hostages in apartment	Phase 3: Apartment to airfield	Phase 4: At the airfield	Phase 5: Post-terrorist attack
C2 Maneuver Agility					
Endeavour Space Complexity	Low	Medium	High	Very High	
Appropriate (Required) C2 Approach	Coordinated	Coordinated	Coordinated	Collaborative	Coordinated
Actual C2 Approach	Conflicted (Independent)	De-conflicted	Conflicted	Conflicted (Anarchic)	
Self-Monitoring					
C2 Approach Space					
– Allocation of Decision Rights	None	Somewhat Narrow	None	Complete Breakdown	
– Distribution of Information	Low (radios only)	Low	None	Incorrect Info	
– Patterns of Interaction	None	Somewhat constrained	None (out of control)	Complete Breakdown	
C2 Approach Agility					
Flexibility		●			
Adaptiveness	No Evidence	No Evidence	No Evidence	No Evidence	
(Lack of) Responsiveness	High	High	High	High	
(Lack of) Versatility	High	High	High	High	
Innovativeness					
Resilience	No Evidence	●	No Evidence	No Evidence	

Figure 7.11: Munich Olympics 1972 Evidence Table

Figure 7.11: Munich Olympics 1972 Evidence Table shows a clear disconnect between the Required C2 Approach and the Actual C2 Approach. It was clear that the Collective failed to realize the complexity of the situation, and failed to adopt any of the C2 Approach Agility enablers: note that a value of “High” is for the “Lack of enabler”. Also note that although there are check marks beside Flexibility and Resilience, these represent isolated incidents in the reported vignettes, and do not refer to the entire phase. The DoI value is “Incorrect Information” during Phase 4. Analysts concluded that distributing incorrect information is worse than not distributing any information. Overall, this case study demonstrated the significance of a lack of C2 Agility.

7.4.7 Vancouver Olympics 2010

This case study focuses on the 2010 Vancouver Olympics. In February and March 2010, the city of Vancouver, British Columbia hosted the Olympic and Paralympic Winter Games (V2010). The Vancouver Organizing Committee for the 2010 Olympic and Paralympic Winter Games (VANOC) led Games operations, the Integrated Security Unit (ISU) led security operations, and Emergency Management British Columbia (EMBC) lead public safety operations. The ISU for the Vancouver 2010 Olympics (V2010) was led by the Royal Canadian Mounted Police and included the Canadian Forces, Vancouver Police Department, and West Vancouver Police Department. Several liaison officers were also deployed to the ISU to coordinate with other organizations or teams that were not a part of the ISU. These included: NORAD, Public Safety Canada and Emergency Management British Colombia.

Organizations involved in providing security for major operations are faced with many challenges that stem from the need to coordinate the activities of multiple supporting organizations and the necessity to be prepared and ready to respond quickly to a variety of incidents. In order to achieve their goal and maintain an adequate level of security, these organizations must display Agility and adaptability to changes and unexpected events. Therefore, the V2010 ISU constitutes an interesting and valuable focus for analysis evidence of Approach Agility, as it involves a well-defined Collective in charge of security for a major international sporting event.

Three analysts worked on the Evidence Table. One of the analysts attended the actual event. They used an Excel spreadsheet to collect the data, very similar to the Munich analysts. However, this group of analysts took a more conservative approach to inferring evidence values. If there was no clear evidence to infer a value then the default was to leave the entry blank.

Before the event (Phase 1), the ISU had three exercises called Bronze, Silver, and Gold where the exercise complexity varied from low to medium high (see Figure 7.12: Vancouver Olympics 2010 Evidence Table).

During the event (Phase 2), the complexity was low since the Olympics ran to plan without any significant incidents. After the event (Phase 3), the complexity (by definition) was low. Thus, based on the complexity/required approach hypothesis, the corresponding required approach would be de-conflicted to collaborative, de-conflicted, and de-conflicted, respectively for each phase (this is an assumption as no evidence was found for the Required C2 Approach in the source documents).

Concept/Component	Phase 1: Before Event	Phase 2: During Event	Phase 3: After Event
C2 Maneuver Agility			
Endeavour Space Complexity	Low to med high	Low	Low
Appropriate (Required) C2 Approach	De-conflict to Collaborative	De-conflicted	De-conflicted
Actual C2 Approach	Started de-conflicted, ended around coordinated	Coordinated	Between De-conflicted and coordinated
Self-Monitoring	Scripted	No opportunity	NA
C2 Approach Space			
– Allocation of Decision Rights	Narrow then somewhat broad	Somewhat broad	None
– Distribution of Information	Broad capability available	Fairly broad	No need to be broad
– Patterns of Interaction	Started constrained, ended somewhat constrained	Somewhat constrained	Constrained
C2 Approach Agility			
Flexibility	No opportunity	No opportunity	NA
Adaptiveness	No opportunity	No opportunity	NA
(Lack of) Responsiveness	●	No opportunity	NA
(Lack of) Versatility	●	●	NA
Innovativeness	No opportunity	No opportunity	NA
Resilience	No opportunity	No opportunity	NA

Figure 7.12: Vancouver Olympics 2010 Evidence Table

ADR was predetermined and the ISU exercised the organizational structure, roles, and responsibilities they were given. Thus ADR and PoI were somewhat broad before and during the event. After the event, ADR was not relevant. At the same time, the ISU had a state-of-the-art Information Sharing system. And so, DoI was potentially very broad. But, in fact, DoI business rules provided some structure and therefore the DoI manifested was fairly broad. The organizational structure was fairly flat. That is, there was a Commander, his Deputy, and then all other personnel were at the same level. Thus, PoI started somewhat constrained, then after exercises and during the event it became somewhat unconstrained, and finally somewhat constrained after the event.

From the assessment of ADR, DoI, and PoI across the phases, one can begin to determine the position in the C2 Approach Space, and therefore the Actual Approach. In this case, the actual approach assessment is fuzzy. That is, the actual approach spans a larger portion of the space venturing into off-diagonal regions. Also, there is uncertainty with respect to the exact location of the C2 Approach in the C2 Approach Space since analysts needed to exercise judgment in cases when the source documentation does not use the language associated with the NATO NEC C2 Maturity Model or with C2 Agility Theory.

Because the Vancouver Olympics were conducted without major incidents, there was little or no opportunity to observe the Agility enablers in action. During the exercises (before the event), one could argue that there was a demonstration of responsiveness and versatility as the ISU engaged in a variety of prefabricated scenarios. Self-monitoring was undertaken externally to the ISU by the exercise white cell. This may be an appropriate model for actual operations: that is, have a small team monitor the C2 along the three dimensions, the complexity of the situation, and make recommendations to transition to the appropriate approach.

7.4.8 Helmand Province 2010/11

Military C2 organizations and structures involved in warfighting operations in Helmand, Afghanistan faced many challenges that stem from the need to 1) coordinate activities of multiple supporting commands and assets as well as 2) respond quickly to a variety of incidents in a counter insurgency (COIN) environment. In order to achieve their objective in terms of desired effects and maintain an adequate level of security, these organizations must display a high degree of Agility, and adapt to changes and unexpected events characteristic of a complex battlespace. Lives depend on it daily.

This case study examines data collected from a specific NATO/ISAF battlespace in the Upper Gereshk Valley, Helmand Province, Afghanistan from August 2010 to January 2011, and area of responsibility belonging to Task Force Helmand. It involves a variety of specific military commands and sub-commands operating within this battlespace with primary focus on a Danish Battlegroup and its five Component Commands, as well as five Special Operations Forces (SOFs) of different varieties operating in the same battlespace. This includes mentored Afghan and Coalition SOFs.

Concept/Enabler	Aug 2010 (Phase 1)	Sept 2010 (Phase 2)	Oct 2010 (Phase 3)	Nov 2010 (Phase 4)	Dec 2010 (Phase 5)	Jan 2011 (Phase 6)
C2 Maneuver Agility						
Endeavour Space Complexity	(Very) High	(Very) High	(Very) High	(Very) High	(Very) High	(Very) High
Appropriate (Required) C2 Approach	Edge	Edge	Edge	Edge	Edge	Edge
Actual C2 Approach	Conflicted	Conflicted	De-conflicted	Edge	Edge	Edge
Self-Monitoring	None	None	None	Recognized the need to change approaches	Recognized the need to change approaches	Recognized the need to change approaches
C2 Approach Space						
– Allocation of Decision Rights	Narrow (isolated)	Narrow (isolated)	Less Narrow (expanding network awareness)	Broad (expanding network awareness)	Broad (expanding network awareness)	Broad (expanding network awareness)
– Distribution of Information	Vertical Narrow Push	Vertical Narrow Push	Vertical/Lateral "push-pull"	Lateral "push-pull"	Lateral Push-pull	Lateral push-pull
– Patterns of Interaction	Tightly constrained	Tightly constrained	Constrained	Unconstrained	Un-constrained	Un-constrained
C2 Approach Agility						
Flexibility	Low	Low	Med	Med High	High	High
Adaptiveness	Low	Low	Med	Med high	High	High
Responsiveness	Low	Low	Med	Med High	High	High
Versatility	Low	Low	Med	Med High	High	High
Innovativeness	Low	Low	Med	Med High	High	High
Resilience	Med High	Med High	Med High	Med High	High	High

Figure 7.13: Helmand Province Evidence Table

Figure 7.13: Helmand Province Evidence Table shows that the Endeavour Space Complexity was very high, which required an Edge C2 Approach. There was a clear progression of the C2 Approach through the six-month period as the actual C2 Approach moved from Conflicted to Edge. That is, the official Collective failed to respond sufficiently to the complex environment in Phases 1 and 2, and began to sub-divide into two C2 Collectives: official and informal. An informal networked sub-Collective began to emerge responding effectively to the complex environment, while the official general Collective C2 became increasingly irrelevant. The informal sub-Collective matured steadily from Phases 3 to 6 with increasing Agility, while the official Collective C2 became incrementally irrelevant. It was as if the single Collective experienced 'mitosis' which was driven by the principle that whatever decisions and actions were taken needed to have an effect towards achieving operational objectives.

7.5 COMMON CONCEPTS AND ENABLERS

This section examines the C2ACM from the perspective of all case studies together. Figures 7.14: Case Study Evidence for C2 Maneuver and Related Concepts and 7.15: Case Study Evidence for the Enablers of C2 Approach Agility summarize the evidence gathered across the case studies.

	Rwanda DPKO	Rwanda Media	Estonia Cyber Attack	Georgia Cyber Attack	Garda Earthquake	Haiti Earthquake	Munich Olympics	Vancouver Olympics	Helmand Province
C2 Maneuver Agility					●				●
Endeavour Space Complexity	●	●	●	●		●	●	●	●
Appropriate (Required) C2 Approach			●				●	●	●
Actual C2 Approach	●	●	●	●	●	●	●	●	●
Self-Monitoring	●	●	●					●	●
C2 Approach Space									
– Allocation of Decision Rights	●	●	●	●	●	●	●	●	●
– Distribution of Information	●	●	●	●	●	●	●	●	●
– Patterns of Interaction	●	●	●	●	●	●	●	●	●

Figure 7.14: Case Study Evidence for C2 Maneuver and Related Concepts

The first part of Figure 7.14 is a summary of evidence for Endeavour Space Complexity and the C2 Approach Space dimensions (and therefore the Actual C2 Approach) that appears in Figures 7.4 – 7.13. These results provide confidence that these concepts are legitimate and observable in Complex Endeavours.

Three case studies inferred C2 Maneuver Agility (transition from one approach to another based on the situation complexity): Helmand Province, the Garda Earthquake, and Rwanda. Helmand Province (Figure 7.13) shows the Required C2 Approach as Edge based on the situation complexity, while the Actual C2 Approach starts Conflicted, passes through De-conflicted, and ends up as Edge. Although Garda did not indicate explicitly the Required Approach, it clearly shows the Actual C2 Approach varying directly with the Endeavour Space Complexity as the C2ACM would predict. Similar to Garda, Rwanda did not indicate explicitly the Required

Approach. However, the Actual C2 Approach tracked the Endeavour Space Complexity in two examples. The first example was between UNAMIR HQ and UN DPKO where the Collaborative approach (the initial C2 approach) was changed to an Edge approach due to an increase of the level of complexity and urgency of the situation. The approach was then moved back to a Collaborative approach when time constraints allowed doing so. The second example was between UNAMIR HQ and Media, where the Conflicted approach was changed to a Coordinated approach as it was assessed to be beneficial to both entities.

The Georgia and Haiti case studies did not report evidence for the Required Approach but reported some movement in the C2 Approach Space. Haiti reported Conflicted to De-conflicted C2 when the complexity was High, and continued to transition upward to Co-ordinated C2 when the Complexity was coming down to Medium to Low (although Coordinated C2 Approach or higher are just as effective for low complexity situations as observed during the Vancouver Olympics, but perhaps not as efficient).

Estonia and Munich did record Required C2 Approaches but did not yield evidence of C2 Maneuver Agility because they were unable to transition to the required approach. Although Estonia and Munich analysts were able to identify the Endeavour Space Complexity and subsequently the Required C2 Approach, they also noted that there was no Self-Monitoring of the Actual and Required C2 Approaches. And so, it seems as if the Actual C2 Approach meandered through the C2 Approach Space without any regulation or control imposed on it. Thus, the Estonia and Munich case studies provided evidence for the lack of C2 Maneuver Agility due to the inability to transition to a specific Required C2 Approach.

For the Vancouver Olympics case, a strategic directive was made that the ISU would be Collaborative. And so, this directive was a strong contributor to the regulation of the Actual C2 Approach along with the Endeavour Space Complexity. Note that the ISU did not reach Collaborative C2 (as defined by SAS-065) but attained Coordinated C2: meanwhile the Required C2 Approach level would be De-conflicted C2 since the complexity was low.

Five out of nine case studies indicated Self-monitoring, which is essential for C2 Maneuver Agility. Out of these five case studies, only Helmand Province demonstrated C2 Maneuver Agility. Of note, the Garda Earthquake yielded C2 Maneuver Agility but gave no evidence for Self-monitoring. One possible reason for this is that the concept of Self-monitoring was added to the C2 Model long after the Garda Earthquake template was completed.

Figure 7.15: Case Study Evidence for the Enablers of C2 Approach Agility looks across the cases to see what the evidence is for the enablers of agility. All, but one case study, reported evidence for Flexibility and Responsiveness. The Vancouver Olympics case study did not report evidence for Flexibility because there was no reason (major disturbance) to exhibit Flexibility. While the overall UNAMIR mission may be characterized as not being responsive to the evolution of the situation, evidences of Responsiveness was found between UNAMIR HQ and UN-DKPO as well as between UNAMIR HQ and the media. And so strictly speaking the case study as a whole did provide evidence for Responsiveness.

	Rwanda DPKO	Rwanda Media	Estonia Cyber Attack	Georgia Cyber Attack	Garda Earthquake	Haiti Earthquake	Munich Olympics	Vancouver Olympics	Helmand Province
C2 Approach Agility	●	●							
Flexibility	●	●	●	●		●	●		●
Adaptiveness	●		●	●	●	●			●
Responsiveness	●		●	●	●	●	●	●	●
Versatility			●		●	●	●	●	●
Innovativeness		●	●	●	●	●			●
Resilience			●		●		●		●

Figure 7.15: Case Study Evidence for the Enablers of C2 Approach Agility

These results would lead us to believe that Flexibility and Responsiveness are vital for C2 Approach Agility where higher values should correspond to Collaborative and Edge C2 Approaches and lower values should correspond to Coordinated and De-conflicted C2 Approaches. Upon closer examination, however, only the Helmand Province case study matches this hypothesized correlation between Actual C2 Approach and C2 Approach Agility. That is, for example, the Munich Olympics reported Flexibility during one of their vignettes, yet the Actual C2 Approach was Conflicted or worse. Thus, it is difficult to draw conclusions between Actual C2 Approach and C2 Approach Agility enablers using these case studies.

In summary, the case studies provide strong evidence for C2 Maneuver Agility and related concepts. The Helmand Province case study provides the most convincing evidence for C2 Maneuver Agility. However, the observed behaviors and outcomes seen in the other case studies may also be explained using the C2 Agility Conceptual Model. In addition, we observed that the existence of Self-monitoring played an important role in C2 Maneuver Agility. Finally, while evidence was found for C2 Approach Agility enablers, there is less clarity in validating the expected relationship between the enabler values and the Actual C2 Approach levels.

7.6 COMPARISONS BY MISSION

Recall that the case studies were grouped into five categories: Peace-Keeping, Cyber Warfare, Natural Disasters, and Major Events, and Complex Battlespace. In this section, pairs of case studies are compared to each other within each category.

Although there is only one case study in the Peace-keeping category, two interactions were analyzed: between the UN and DPKO, and the UN and media. This is an important case study as it is the only one that looks at C2 Agility and C2 Approach Agility within "Self". That is, the C2ACM can be applied to not only Collective-environment[107] interaction, but also interaction between Entities within the Collective.

Cyber Warfare endeavours are highly complex primarily because of the uncertainty. Cause and effect relationships, and how disruptions in cyberspace would impact physical and societal spaces, are nearly impossible to predict in cyberspace. Traditional C2 methods are difficult to apply because the Collective might not know who is on the "team" at any given time. Flexibility, Adaptability, Responsiveness, and Innovativeness seem to be key enablers in these case studies, and both sides of the conflict possess these traits.

Natural Disaster case studies provide a good opportunity to compare and contrast two responses to an earthquake event. The Garda Earthquake response exemplifies C2 Maneuver Agility (transitioning from one approach to another based on the situation complexity) while the Haiti Earthquake Collective needed to be more Coordinated and Collaborative but did not achieve these C2 Approaches. The Garda success is primarily attributed to the community's preparation and training in the event of an earthquake, unlike the Haitian community with no apparent Earthquake response plan. Also, the Garda Earthquake relied solely on internal Italian resources while the Haiti Earthquake relied almost exclusively on international aid. Thus, the international Collective had additional factors to contend with including complexity in "Self" and a relatively unknown environment. Because of this, the Haiti Earthquake Collective needed to be quite innovative.

The Major Event case studies highlight, on one hand, the lack of C2ACM concepts and enablers, and on the other hand, the lack of a change in circumstances that required C2 Agility. Olympics security in general has adopted a learning culture to prevent incidents like Munich. Host cities are chosen far enough in advance that security personnel have the opportunity to attend the Olympic event four years before their own, and observe firsthand security operations. For the Vancouver Olympics, there were a number of full scale security exercises where the Interagency Security Unit (ISU) walked through a number of possible scenarios. Like Garda, the ISU was ready. C2 Agility (particularly C2 Maneuver Agility) is not observed when no significant change in circumstances occurs.

Only one case study was completed for the Complex Battlespace category. Evidence for the C2ACM was easier to find since most of the model terms have their origins in military organizations, and NATO has already adopted some of these terms. This, in fact, highlights the difficulty in collecting evidence from other case studies that do not use C2ACM terms in their operations. Case study analysts must interpret, decode, and "translate" the source documents to try to relate them to the Model. As always going from one language to another, things get lost in translation.

[107] It could be argued that the media is part of the environment as a friendly, neutral, or adversary entity.

7.7 ADDITIONAL CONCEPTS AND ENABLERS

Case study leads were provided an opportunity to identify and report new concepts and enablers. Once an observation of an instance involving a new concept was reported, other case study analysts decided whether the concept was present within their study. Case study evidence related to each new concept is presented in Figure 7.16: Case Study Evidence for New Concepts and discussed briefly below.

	Rwanda DPKO	Rwanda Media	Estonia Cyber Attack	Georgia Cyber Attack	Garda Earthquake	Haiti Earthquake	Munich Olympics	Vancouver Olympics	Helmand Province
Anticipation	●	●							
Leadership	●	●	●	●		●	●		●
Collective changes	●		●	●	●	●			●
C2 Approach Heterogeneity									
Comfortable C2 Approach	●		●	●	●	●	●	●	●
Risk Assessment									
Competency as an enabler			●		●	●	●	●	●
Trust and Relationships		●	●	●	●	●			●
Conflicted vs. Independent C2									
Politically driven C2 Approach			●		●		●		●
Off-diagonal C2 Approaches									
C2 Agility emergent									

Figure 7.16: Case Study Evidence for Additional Concepts

7.7.1 Anticipation

Anticipation (Learning, Training, Exercises) as an enabler was debated within SAS-085. However, it was felt that anticipation was not a 'stand- alone' enabler in fact contributor to one or more of the six enablers. Clearly, anticipation can improve Responsiveness and may provide time to identify and prepare additional options and thus increase Flexibility. A similar argument could be made that links anticipation to Innovation.

Anticipation manifests itself before the event or between two events and not during an event where Agility would be manifested. And so SAS-085 considered the concepts of Potential and Manifest C2 Agility. Potential C2 Agility would include enablers that would help the organization prepare to be agile, while Manifest C2

Agility would be measurable and observable Agility during an event. Potential C2 Agility is linked to the concept of Requisite Maturity in that the Collective must possess a certain C2 Maturity to manifest C2 Agility and C2 Approach Agility. Anticipation could be categorized as part of Potential C2 Agility because it occurs typically between events. On the other hand, a Commander may engage in some anticipatory behaviors during the event.

7.7.2 Role of Leadership

Leadership or a lack thereof was found to be significant in achieving, determining, or maintaining C2 Maneuver Agility or C2 Approach Agility in six out of the nine case studies. The entry for the Munich Olympics is a minus and check to denote that poor Leadership led to a lack of C2 Maneuver Agility and C2 Approach Agility. The Vancouver Olympics was the most obvious case of a positive relationship for the role of leadership because the political leadership mandated the Interagency Security Unit to be Collaborative, and every effort was made to attain this goal.

7.7.3 Size of Collective

Collective size changing over time is a new concept that impacts C2 Agility. The Helmand Province and Garda Earthquake Collectives adopted Edge C2 as required. However, these Collectives were relatively small and homogeneous compared to other case study Collectives where larger Collectives required more effort, communications, and information sharing to govern / manage the internal workings of the organization, thus diverting energy from becoming more agile.

7.7.4 Homogeneity of C2 Approach

C2 Approach homogeneity amongst Entities within the Collective enables Agility while Collectives whose entities adopt different C2 Approaches tend to have difficulties manifesting Agility. The Rwanda case study reported that UNAMIR employed different C2 Approaches with different organizations depending on the maturity level of the contingent as well as the level of trust that existed between and among the leaders: Conflicted C2 with Banglaseshi contingent, Deconflicted C2 with France, Coordinated C2 with Ghana, and Collaborative C2 with Belgium. Similarly, national, provincial, and municipal police along with military forces and other security organizations for the Vancouver Olympics recognized that they all had very different ways of operating. And so, several exercises were conducted before the Olympics to develop a common C2 Approach for this event, or at the very least understand the differences that existed.

7.7.5 Comfortable C2 Approach

The notion of a 'Comfortable' C2 Approach was highlighted in both the Haiti and Vancouver case studies. That is, an Entity may be familiar with a certain C2 Approach (e.g., De-conflicted) and then they are put into situations that are more Edge-like. This creates a reluctance to change to the new approach. Note that, the reverse is true if an Entity is used to being Edge-like and the situation requires a more De-conflicted approach, there will still be some reluctance to change.

7.7.6 Risk Assessment

Risk Assessment is a new concept observed during the Rwanda Genocide case study analysis. General Dallaire weighed the risks of a potential genocide before facilitating media information access and therefore focusing world opinion on the Rwanda operation. After receiving the order to redraw, General Dallaire weighted the risks of UNAMIR member's lives against the potential of saving Rwanda lives when proposing to UN DPKO a new option to maintain a minimal force in Rwanda. This relationship between risk and Agility requires further exploration.

7.7.7 Competency

The importance of a Competency enabler for Agility was evident in the Estonia, Georgia, and Garda case studies. An agile organization must have competency in not only performing tasks but also allocating decision rights, distributing information, facilitating interactions between Entities within the Collective. For Estonia and Georgia, we see that special skills (computer hacking) were employed to cope with the nature of these conflicts. The Requisite Variety in Skills and Resources necessary to cope with the complexity and dynamics of the situation are related to this new enabler.

7.7.8 Trust

Garda showed that Trust and Interpersonal relationships are key human factors variables related to Agility. The entry for the Munich case study is a "minus check" to indicate the existence of distrust and non-healthy interpersonal relationships amongst Entities that led to a lack of C2 Agility.

7.7.9 Conflicted v Independent v Anarchical C2

The term "Conflicted C2" did not seem to some to be the best term to use in the Munich case study, although by definition it was the appropriate designation as there was no Collective C2 observed (ADR was none, DoI was none, and PoI was highly constrained and the entities within the Collective were acting independently than in conflict and were making decisions on their own. Some members of the case study team preferred the term "Independent C2" which corresponds to the NATO NEC Capability level "Stand Alone Operations"[108]. Case study analysts used the term "Anarchical C2" when DoI was "somewhat broad" but erroneous. An effort to further define and refine the semantics of Collective C2, particularly when there are heterogeneous approaches to C2 across a Collective, would prove useful.

7.7.10 C2 Approach Selection

The approach to C2 that is adopted (Actual C2 Approach) can be influenced by politics as well as by a consideration of the mission and circumstances. The Vancouver case study clearly showed that the selection of a C2 approach may be directed by higher authorities. In this case, situation complexity would seem to suggest a De-conflicted C2 Approach while a Collaborative C2 Approach was mandated. The approach observed (the Actual C2 Approach) ended up somewhere between these two. This phenomenon has been explored using modeling and simulation in (Farrell, 2011).

[108] See NATO NEC C2 Maturity Model, Figure3: Level of Maturity and NNEC Capability Levels, p.46

7.7.11 Off-diagonal C2 Approaches

The Rwanda, Haiti, and Vancouver case studies involved off-diagonal approaches, or at least a range of observed positions in the C2 Approach Space that included off-diagonal approaches. This highlights the difficulty of identifying more precise values of ADR, DoI, and PoI within the source documents. It also highlights to the dynamic nature of the C2 Approach Space dimensions in that they are rarely in one position in the C2 Approach Space over time as well as different Entities will have different individual values at any given time, thus making ADR, DoI, and PoI difficult to measure or aggregate over the entire Collective and over time.

The Helmand Province case study reported C2 Maneuver Agility and C2 Approach Agility as an emergent phenomenon rather than pre-designed before the operation, which would be expected for military endeavours. In many ways, SAS-085 has formalized what successful military Collectives and operations have done instinctively.

7.8 C2 AGILITY HYPOTHESES FROM CASE STUDY PERSPECTIVE

The analysis conducted across the case studies addressed the existence of evidence that supported (or refuted) the C2 Agility hypotheses. Although some general hypotheses were discussed early in the SAS-085 effort, the 12 specific hypotheses, which can be found in Section 4.12 C2 Agility Hypotheses, were developed after the Case Study Template was produced and, in some cases, after case studies were analyzed and completed. And so, any evidence that was found to support these specific hypotheses came fortuitously and not by *a priori* design.

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

In general, case studies were able to identify an ordinal value for ADR between none and broad, DoI between none and broad, and PoI between constrained and unconstrained that, together, correspond to the expected values of the given C2 Approach (see Chapter 2 - Orientation). These ordinal values place each of the C2 Approaches in distinct regions of the C2 Approach Space, therefore, the case studies would support this hypothesis.

7.8.2 H2: No one C2 Approach to C2 is always the most appropriate

Only the Garda case study showed that no one approach to C2 is always the most appropriate. That is, as the situation complexity changed from high to medium/low, the Collective recognized this change and maneuvered in the C2 Approach Space from Edge to Coordinated. In other words, the Collective did not stay at Edge (although Edge would have solved the problems at lower complexity levels) because Edge would not have been as efficient. On the other hand, the Vancouver case study hinted at the converse of this hypothesis when the Collective adopted a Coordinated C2 Approach even though the appropriate approach wandered between De-conflicted and Coordinated. The Collective did not maneuver between these two approaches but rather (in C2ACM terms) the Coordinated C2 Approach was agile enough that it was able to cope with all circumstances to which the Collective was exposed.

7.8.3 H2: 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

Both the Helmand Province and Garda case studies showed that more network-enabled C2, in this case Edge C2, was the appropriate approach when the situation complexity was (very) high as the employment of the Edge approach seemed to produce the desired mission outcomes.

7.8.4 H4: More network-enabled approaches to C2 are more agile (possess more C2 Approach Agility)

The hypothesis examines the correlation between Actual C2 Approach and C2 Approach Agility and its enablers. The hypothesis suggests that as the Actual C2 Approach moves from Conflicted to Edge, C2 Approach Agility (or their enablers) would monotonically improve. Figure 7.17: Actual C2 Approach and C2 Approach Agility compares the Actual C2 Approach alongside C2 Approach Agility for select phases of each of the case studies. The phases that were omitted did not add any additional insight to this hypothesis because either no evidence was found for C2 Approach Agility for that phase, or the information that was provided was duplicated for a previous phase.

Helmand Province (H) shows the expected correlation: that is, as Actual C2 Approach moves from Conflicted through De-conflicted to Edge, the C2 Approach Agility enablers monotonically increase from low through medium to high. However, this is where the correlation ends. One might argue that Munich (F) tends to support the antithesis of this hypothesis, however, there is only a single piece of evidence to formulate any conclusion about this case. The Haiti case study (E) clearly shows unexpectedly that although the Collective was at best De-conflicted, the C2 Approach Agility enablers are relatively high. That is, by definition the Entities in the Collective were formally operating within their lanes but individuals (regardless of organizational affiliation) did whatever they could to save lives regardless of their organizational affiliations. The Agility of individual Entities may be able to compensate for the lack of Agility of the Collective. There was very much an informal under-current of emergent behaviours and Self-synchronization that one might consider “edge”-like. Overall the case studies do not provide sufficient evidence that more network-enabled C2 Approaches are more agile.

<table>
<tr><th rowspan="2">Case Study Selected Phases</th><th rowspan="2">Actual C2 Approach</th><th colspan="6">C2 Approach Agility</th></tr>
<tr><th>Flexibility</th><th>Adaptiv.</th><th>Responsiv.</th><th>Versatility</th><th>Innovativ.</th><th>Resilience</th></tr>
<tr><td>Rwanda UN DPKO Phase 1</td><td>Collaborative</td><td colspan="6">Low</td></tr>
<tr><td>Rwanda UN DPKO Phase 2</td><td>Collaborative</td><td colspan="6">High</td></tr>
<tr><td>Rwanda UN DPKO Phase 3</td><td>Collaborative</td><td colspan="6">Low</td></tr>
<tr><td>Rwanda UN DPKO Phase 4</td><td>Collaborative</td><td colspan="6">Low</td></tr>
<tr><td>Rwanda Media Phase 1</td><td>Conflicted</td><td colspan="6">Low</td></tr>
<tr><td>Rwanda Media Phase 2</td><td>Conflicted/Coordinated</td><td colspan="6">High</td></tr>
<tr><td>Rwanda Media Phase 3</td><td>Coordinated</td><td colspan="6">Low</td></tr>
<tr><td>Rwanda Media Phase 4</td><td>Coordinated</td><td colspan="6">Low</td></tr>
<tr><td>Estonia Phase 1 cyber</td><td>Collaborative</td><td>High</td><td>Low</td><td>High</td><td>Med</td><td>Med</td><td>Low</td></tr>
<tr><td>Georgian</td><td>Collaborative - De-conflicted</td><td></td><td>High</td><td>High</td><td>High</td><td></td><td></td></tr>
<tr><td>Garda Phase 1</td><td>Edge</td><td></td><td></td><td>●</td><td>●</td><td></td><td>●</td></tr>
<tr><td>Garda Phases 2& 3</td><td>Collaborative-Coordinated</td><td></td><td>●</td><td></td><td></td><td>●</td><td>●</td></tr>
<tr><td>Haiti Phase 1</td><td>Conflicted-De-conflicted</td><td>High</td><td>High</td><td>High</td><td>Medium</td><td>High</td><td></td></tr>
<tr><td>Munich Phase 2</td><td>De-conflicted</td><td>●</td><td></td><td>—High</td><td>—High</td><td></td><td>●</td></tr>
<tr><td>Vancouver Phase 2</td><td>Coordinated</td><td></td><td></td><td></td><td>●</td><td></td><td></td></tr>
<tr><td>Helmand Phase 1</td><td>Conflicted</td><td>Low</td><td>Low</td><td>Low</td><td>Low</td><td>Low</td><td>Med High</td></tr>
<tr><td>Helmand Phase 3</td><td>De-conflicted</td><td>Med</td><td>Med</td><td>Med</td><td>Med</td><td>Med</td><td>Med High</td></tr>
<tr><td>Helmand Phase 5 & 6</td><td>Edge</td><td>High</td><td>High</td><td>High</td><td>High</td><td>High</td><td>High</td></tr>
</table>

Figure 7.17: Actual C2 Approach and C2 Approach Agility

7.8.5 H5: The dimensions of the C2 Approach Space are positively correlated with Agility

Unlike the experimental validation, no single Agility number was derived for the case studies that could be then correlated to the nominal values of ADR, DoI, and PoI. And so, the case studies cannot address this hypothesis.

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

Case study analyses were more focused on C2 Maneuver Agility where analysts were looking for instances where Collectives moved around the C2 Approach Space. And so, the case study results did not address this hypothesis.

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

Rwanda, Haiti, and Vancouver all reported off-diagonal C2 Approaches, but did not make any determination on the Agility of these approaches. Thus, the case studies do not provide any additional insight into this hypothesis. Analysts simply accepted off-diagonal approaches as what will occur in real situations, and that balanced approaches are constructs to help understand the model. At the same time, the N2C2M2 depicts the C2 Approaches as nebulous regions that, by definition, includes some of these off-diagonal (or more precisely near-diagonal) approaches.

7.8.8 H8: Increasing C2 Maneuver Agility increases Agility

In general the case studies and experiments focused on C2 Maneuver Agility and C2 Approach Agility, respectively. One would expect that the case study analyses would yield supporting evidence for this hypothesis. However, only Helmand Province and the Garda Earthquake reported evidence of the ability of an Entity to change over time its approach to C2 to a more appropriate one. The Rwanda Genocide, Georgia Cyber-Attack, and Haiti Earthquake did not find enough evidence to report the Required C2 Approach. Although in all three cases there was movement in the C2 Approach Space, there was not clear evidence on whether the Collective transitioned to the appropriate C2 Approach which, by definition, is C2 Maneuver Agility.

The Estonia Cyber-Attack reported a Required C2 Approach of Co-ordinated or Collaborative for the cyber portion and for all three phases, and Coordinated for the wider enterprise. However, the Actual C2 Approach was steady at Collaborative for the cyber portion, and De-conflicted for the wider enterprise. For the cyber portion, Entities adopted the appropriate approach even though the transition itself was not observed. For the wider enterprise, the Collective did not reach the appropriate approach, and therefore was not agile.

The conclusions for the Munich Olympics are similar to the wider enterprise. That is, the Required C2 Approach was consistently between Coordinated and Collaborative, however, the Actual C2 Approach was Conflicted, De-conflicted, and “Worse than Conflicted”. The Collective failed to maneuver to the appropriate approach. The Vancouver Olympics did not need to transition since the Required C2 Approach was De-conflicted and the Actual C2 Approach was Coordinated. This Collective took advantage of the fact that a Coordinated C2 Approach was just as effective in low complexity situations as would a De-conflicted approach.

In summary, the case studies provide evidence to support this hypothesis. That is, there are two key aspects of C2 Maneuver Agility: identifying the Appropriate C2 Approach and transitioning to the appropriate approach. Helmand Province and Garda yielded evidence for both these aspects. Rwanda, Georgia, and Haiti were able to transition but not necessarily to the appropriate approach. Estonia and Munich identified the appropriate approach were not able to transition, and Vancouver had no need to transition. The outcomes reflected their need and ability to successfully manoeuvre.

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

Unfortunately, analysts were not asked to observe the number of C2 Approaches Entities had in the C2 ‘toolbox’. An observer could imply this number if a case study had reported several Actual C2 Approaches. However, in most cases, only one or two Actual C2 Approaches were required. Thus, there was not sufficient evidence to support this hypothesis.

7.8.10 H10: Self-monitoring is required for C2 Maneuver Agility

From Figure 7.14, the Helmand Province, Rwanda, Estonia, and Vancouver case studies reported evidence of Self-monitoring. However, there is a sense when reading through the studies that the Collective tends to stay at a Conflicted or De-conflicted level when there is no monitoring of Self or the environment. Thus, the case study results would support the notion that Self-monitoring is a key aspect of C2 Maneuver Agility.

7.8.11 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

Figure 7.14 provides data that address this hypothesis. (Lack of) Responsiveness was observed in all case studies. Flexibility was observed in all, except the Vancouver Olympics where there was no opportunity to observe Flexibility. Adaptability and Innovativeness were identified in all except the two major events. Versatility and Resilience were noted in six and four case studies, respectively. In all cases completed, one or more of the enablers of Agility were noted. However, in only two of the cases was C2 Approach Agility reported. In one these cases, all six of the enablers were noted and in the other, four of the six were noted. However, as noted in H4 and H5, it is difficult to correlate these enablers to any measure of Agility. Thus, the case studies would agree that the six enablers are collectively exhaustive but cannot comment on whether observed Agility can be traced to one or more of these enablers.

7.8.12 H12: Each of these enablers is positively correlated with Agility

Referring to Figure 7.17, the Helmand Province and Munich case studies clearly support this hypothesis, while it is not so clear for the other case studies. Thus, no comment can be made regarding this hypothesis from a case study perspective.

7.9. CASE STUDIES SUMMARY

Figures 7.14 and 7.15 summarizes the evidence for the C2ACM concepts and enablers obtained from the case studies. Evidence is found for all of the key C2 Agility concepts and enablers. This generated confidence in the model described in Chapter 3 Basics of Agility and Chapter 4 C2 Agility.

However, it is important to remember that this evidence was collected from source documents that did not explicitly use the model’s terms and definitions, thus requiring case study analysts to infer the existence and value of the concept and enabler based on their intimate knowledge of the case.

Figure 7.16 provided a list of concepts and enablers that should be integration into the C2ACM:

- Anticipation as an Agility enabler
- Role of Leadership
- Collective Size changing over time
- Each Entity operating with a different C2 Approach
- ‘Comfortable’ C2 Approach
- Risk Assessment
- Competency as an Agility enabler
- Skill and Resources Requisite Variety
- Trust and Personal Relationship
- Role of Compromise
- More research on Conflicted C2
- Politically driven C2 Approach
- Off-diagonal C2 Approaches
- C2 Maneuver Agility and C2 Approach Agility as an emergent phenomenon

The final meta-analysis involved commenting on the C2 Agility hypotheses. Figure 7.18: C2 Hypothesis Findings: Case Studies summaries the C2 hypothesis findings from the case studies.

Hypothesis	Evidence Found
H1: Distant C2 Approaches	Yes
H2: No ‘one-size’	Not clear
H3: Network-enabled - Challenging	Yes
H4: Net-enabled - Agility	Insufficient
H5: Approach Space – Agility	n/a
H6: Network-enabled - Position	n/a
H7: on v off diagonal C2 Approaches	n/a
H8: C2 Maneuver - Agility	Yes, limited
H9: C2 Maturity - Agility	Insufficient
H10: Self-monitoring - Agility	Yes
H11: Components	Yes, limited
H12: Components - Agility	Yes, selected cases

Figure 7.18: C2 Hypothesis Findings: Case Studies

7.10 CASE STUDY REFERENCES

SAS-065. (2010). *NATO NEC C2 Maturity Model Overview*. Paris: NATO RTO. CCRP Publication series.

Farrell, P. S. E. (2011). *Organizational Agility Modelling and Simulation*. Paper presented at the 16th International Command and Control Research and Technology Symposium: Collective C2 in Multinational Civil-Military Operations. Quebec City, Canada.

Chapter 8 - FINDINGS, CONCLUSIONS, WAY AHEAD

8.1 GENERAL FINDINGS AND CONCLUSIONS

Based upon an analysis of the empirical evidence from case studies and experiments, SAS-085 concluded that

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Agility is a critical capability that can and should be pursued by NATO, its member nations, and mission partners.

It is desirable to increase C2 Agility because doing so improves the likelihood of mission success. Increased C2 Agility contributes to mission success by enabling entities to adopt more appropriate approaches to C2 in more situations and to adjust their approaches as the mission and circumstances change. Improving C2 Agility is feasible because 1) the concepts have proven to be readily understandable, 2) C2 Agility and the variables that impact it are observable, are measureable, and can be influenced or controlled by entities.

SAS-085 also concluded, that based upon the variety of missions, circumstances, and collections of entities needed to meet these varied challenges, that there is no "one-size-fits-all" approach to C2 and therefore, that entities need to be able to employ more than one approach, understanding when different approach are appropriate, and have the ability to efficiently transition between C2 Approaches efficiently in a timely manner.

There are a number of ways to improve C2 Agility

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C2 Agility can be increased by 1) expanding the number and variety of C2 Approaches an Entity can choose among (a larger, more diverse C2 Approach 'toolkit'), 2) enabling Entities to select and adopt the most appropriate approach to the mission and circumstances (improving C2 Maneuver), and 3) making individual C2 Approaches and the systems that support them more responsive, versatile, flexible, and resilient and making individuals and organizations more adaptive and innovative.

8.2 C2 AGILITY HYPOTHESES RESULTS

These general findings and conclusions are accompanied by a set of more specific findings related to the characteristics of specific C2 Approaches and the ability of an Entity to adopt these approaches that have been expressed in the form of C2 Agility Hypotheses. The findings drawn from the empirical evidence from case studies and experiments and their practical implications are summarized below.

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

Both the case studies and the experiments found support for this hypothesis. Although the available documentation used for the case studies did not explicitly refer to either the NATO C2 Maturity Model C2 Approaches or to the dimensions of the C2 Approach Space, the analysts were able to relate the C2 Approaches employed by the Entities involved to regions of the C2 Approach Space.

Although the simulated Entities' location in the C2 Approach Space was dependent upon the different measures used and was affected by the stresses entities were subjected to, an analysis of the positions observed for each C2 Approach over a fairly large set of runs formed visibly and statistically distinct clusters. Nevertheless, several of the C2 Approaches occupied overlapping regions of the C2 Approach Space. Two major factors are responsible for these overlaps. First, the verbal descriptions in the NEC C2 Maturity Model are not precise enough to eliminate overlaps in the regions since they can be instantiated is a variety of ways. Thus, using quantitative measures of the approach dimensions is needed to disambiguate similar approaches. Second, overlaps can be traced to disturbances that moved the Entity's intended location in the C2 Approach Space by interfering with Patterns of Interaction and/or Distribution of Information.

So What: There is more than one approach to C2. Therefore, Commanders need to become aware of this fact and recognize how C2 is being approached.

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

The case studies found that the complexity of the situation dictated the most appropriate approach to C2 and that this complexity varied over phases of the endeavour. In all cases, there were multiple approaches to C2 that were appropriate at different times. In the campaign of experimentation, there were missions/circumstances where both less network-enabled and more network-enabled approaches were appropriate (successful and least cost). The case studies also noted that the size of the Collective changes over time and that the appropriate C2 Approach may change as well as a function of size.

So What: Commanders should not assume that their current approach will always work.

8.2.3 H3: More network-enabled approaches to C2 are more appropriate for Complex Endeavors while less network-enabled approaches to C2 are more appropriate for less complex missions/circumstances

It was clear in both the case studies and the experiments that the more complex the situation the more network-enabled approaches were required while in less challenging situation, less network-enabled approach were sufficient.

So What: If an entity anticipates being involved in Complexity Endeavours, then it should try to develop more network-enabled approaches.

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

In most of the case studies, it was observed that Entities adopted less rather than more network-enabled approaches initially and that in many of these situations they needed to change their approach to a more networked enabled one in order to cope with the situation complexity.

In the series of experiments, calculated Agility scores increased monotonically as C2 Approaches became more network-enabled. Further, these results indicated that improvements in the Agility of C2 Approaches accelerated as they became more network-enabled.

So What: If one can only adopt a single approach to C2, then an entity should adopt the most network-enabled approach it can.

8.2.5 H5: The dimensions of the C2 Approach Space are positively correlated with the Agility of C2 Approaches

An analysis of experimental results shows that the dimensions of the C2 Approach Space are all positively correlated with Agility. Furthermore, their combined impact (location in the C2 Approach Space) explains 50% (linear regression model) and 75% (non-linear regression model) of the variation in the measure of Agility.

So What: same as H4

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

There is not sufficient evidence to support this hypothesis, although it appears that in some of the experiments Edge approaches were not as affected by changes in circumstances as coordinated or collaborative approaches. In some of the experiments, an Entity's position in the C2 Approach Space was seen to vary as a function of circumstances. As the level of stress increased, observed positions in the C2 Approach Space departed from their ideal or intended positions by a greater amount.

So What: All C2 Approaches are subjected to stresses that can impact their intended 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 and how their locations may be affected.

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

An analysis that compared the locations of simulated instances found that the Agility scores of those that were close to the diagonal were significantly higher than those that were far from the diagonal.

So What: There is a need to maintain balanced between and among the dimensions of the C2 Approach Space.

8.2.8 H8: Increasing C2 Maneuver Agility increases Agility

Two of the cases studied reported evidence of the ability of an Entity to change over time its approach to C2 to what was perceived as a more appropriate one; but, given the fact that these were cases studies the impact on agility could not be definitively ascertained.

So What: 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.

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

There is evidence but it is not sufficient to support this hypothesis.

So What: We need more experimentation and analysis

8.2.10 H10: Self-monitoring is required for C2 Maneuver Agility

There are four case studies that observed Self-monitoring, but only one of the four resulted in a movement in the C2 Approach Space. In the other cases, where there was no Self-monitoring, there was no maneuver. This tentatively support a conclusion that Self-monitoring is necessary but not sufficient for C2 Maneuver Agility.

So What: 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

8.2.11 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

In all cases completed, one or more of the enablers of Agility were noted. However, in only two of the cases was the Agility of a C2 Approach reported. In one of these cases, all six of the enablers were noted and in the other, four of the six were noted.

So What: We need to more work on observing the presence or absence of the enablers and their impact on outcomes.

8.2.12 H12: Each of the six enablers is positively correlated with Agility

Two case studies provide evidence to support this hypothesis. In at least one case study, indicators have been identified to be associated with each of the enablers.

So What: More work needs to be done.

Figure 8.1: C2 Hypothesis Findings provides an overview of the findings from both the case studies and the experiments.

Hypothesis	Case Study Evidence Found	Experiments Evidence Found
H1: Distant C2 Approaches	Yes	Yes, high
H2: No 'one-size'	Not clear	Yes, medium
H3: Network-enabled - Challenging	Yes	Yes, medium
H4: Net-enabled - Agility	Insufficient	Yes, high
H5: Approach Space – Agility	n/a	Yes, med-hi
H6: Network-enabled - Position	n/a	No
H7: on v off diagonal C2 Approaches	n/a	Yes, low
H8: C2 Maneuver - Agility	Yes, limited	n/a
H9: C2 Maturity - Agility	Insufficient	Yes, low
H10: Self-monitoring - Agility	Yes	n/a
H11: Components	Yes, limited	n/a
H12: Components - Agility	Yes, selected cases	n/a

Figure 8.1: C2 Hypothesis Findings

There is a considerable amount of agreement between the findings from the retrospective case studies and the simulation-based experiments. Furthermore, each hypothesis finds some support from either the case studies or the experiments. That, having been said, it remains the case that far more empirical evidence is needed to understand the strength of these findings and the conditions under which they are valid. Several other observations from the cases studies are worthy of note. Strong evidence from the case studies indicated the role of leadership in determining, positively or negatively, the Agility that was manifested. The case studies team observed that there were instances where more than one C2 Approach was being employed by different entities within a Collective or indeed, within a single entity involved in multiple functions or interactions with other entities. In conclusion, SAS-085 has articulated and validated a conceptual model of C2 Agility and related metrics that are clear and understandable and can be used to measure, assess and improve Entity C2 Agility.

8.3 WAY AHEAD

Having concluded that improving C2 Agility is both desirable and practical, the members of SAS-085 considered how the theory could be translated into practice, as expeditiously as possible. That is, ways to "operational" C2 Agility.

Although much can be accomplished or at least initiated in the short run, other efforts will either depend upon laying the necessary foundation. Therefore, Operationalizing C2 Agility will require a sustained effort.

8.3.1 Short Run

In the short run efforts should be undertaken to:

- increase awareness of the need for C2 Agility and the ways in which it can be improved by: providing seminars, workshops, and tutorials; developing modules for courses in military staff colleges and academies; incorporating Agility into training exercises; producing both theory and 'how to' books and articles
- identify what different NATO organizations and member nations are doing to better understand and improve C2 Agility (e.g. Annex C: Overview of UK C2 Agility Work)
- assess the levels of Potential Agility in military organizations and their partners by: creating C2 Agility Assessment protocols; establishing one or more NATO Agility Assessment Teams; conducting assessments and review results with organization(s) interested in improving their Agility; and, documenting these assessments making them accessible to NATO organizations, member nations, and partners.
- Develop a set of Agility-related lessons learned by documenting instances where Agility has been required in operations, the degree to which it was manifested, and the impact on the mission
- use serious games in an effort to assess and improve team and/or individual agility
- develop a set of measurable dimensions for the Endeavor Space and instantiate
- identify the cost drivers related to developing improved agility
- identify the changes to Policy and Doctrine that are needed to remove impediments to Agility as well as those needed to encourage and facilitate Agility

8.3.2 Mid to Long Term

In the mid-term to longer term, attention should be focused on efforts to;

- develop and deploy tools to help organizations improve their C2 Agility by developing a Commander's C2 Agility Handbook, a C2 Approach Space Locator Guide, an Endeavour to C2 Approach Space

Mapping Guide, an Enablers of Agility Checklist, and C2 Maneuver Guidelines and Procedures

- develop systems and decision aids that support Agile Planning and provide ‘common operational pictures’ of the Endeavor and the C2 Approach Space
- improve our ability to conduct C2 Agility-related research by: creating appropriate venues and enhancing the ability of existing venues; developing imbedded capabilities to collect C2 Agility metrics; improving the capability of simulation models to represent / manipulate C2 Approaches, C2 Maneuver, and the Endeavor Space
- undertake collaborative research, experimentation, and analysis
- incorporate Agility related observations and assessments in NATO and member nation Lessons Learned processes

GLOSSARY

ADAPTABILITY[109] (AN ENABLER OF AGILITY)

The ability to change the organization and/or work processes. (adapted from David S. Alberts & Hayes, 2003).

AGILITY

Agility is the capability to successfully effect, cope with and/or exploit changes in circumstances Also see C2 Agility, Approach Agility (the Agility of a C2 approach), Maneuver Agility, Agility Map, Agility Metric

AGILITY, ENABLERS OF

The six enablers of Agility are: Responsiveness, Versatility, Flexibility, Resilience, Adaptability and Innovativeness. The ability of an Entity to manifest Agility or its failure to manifest Agility can be traced to the presence / or absence of one or more of these enablers.

AGILITY MAP

A graphically representation showing the region(s) in the Endeavour Space where an Entity can successfully operate. The map may be drawn for an Entity, a single approach, or a selected set of approaches.

AGILITY METRIC

A way of measuring the degree of Potential Agility possessed by an Entity or C2 Approach. One such metric, used in this report, is a simple scalar measure of Agility, where the degree of Agility equals the ratio of the total volume of the region(s) in the Endeavour Space where an Entity can successfully operate to the total volume of the Endeavour Space.

ALLOCATION OF DECISION RIGHTS (ADR)

In a collection of Entities, the allocation of decision rights reflects the actual rights exercised by the Entities in a Complex Endeavour. This allocation can be the result of explicit or implicit laws, regulations, roles, and practices or it can be as a result of emergent behaviour. The allocation of the rights of participating Entities to the Collective can likewise be explicit, implicit or emergent. An allocation of a right to the Collective refers to the degree to which individual Entities have given up their respective rights for the benefit of the endeavour as a whole (SAS-065, 2010)

[109] Others use Adaptiveness to mean what we mean by Agility.

CIRCUMSTANCE

The conditions under which a mission is performed. This includes for example external stresses such as weather and jamming as well as internal conditions such as the availability of information and performance of one's C2 systems.

COMMAND AND CONTROL (C2)

a *function*, one that includes the allocation of decision rights across the enterprise, the shaping of enterprise decision-making processes and the processes that acquire, manage, share, and exploit information in support of individual and Collective decision making.

C2 APPROACH

One of the possible ways to accomplish the functions associated with C2. A particular C2 Approach corresponds to a region in the C2 Approach Space

C2 APPROACH, APPROPRIATE

A C2 Approach that is able to successfully operate given a specific mission or task, and set of circumstances.

C2 APPROACH MATURITY

More mature approaches to C2 are more network-enabled.

C2 APPROACH SPACE

A three dimension "option" space whose axes correspond to the dimensions of an approach to C2. These dimensions, which are not independent, relate to 1) the way decision rights are allocated across an enterprise, 2) the permissible interactions among Entities within the enterprise and permissible interactions between enterprise Entities and others, and 3) the way information flows and is disseminated.
Source: NATO SAS-050. These three dimension are abbreviated as: ADR, PoI and DoI

C2 APPROACH, ON/OFF-DIAGONAL

Depictions of increasingly network enabled C2 Approaches in the C2 Approach Space locate these approaches along a diagonal of the cube. This diagonal represents balanced or co-evolved approaches where PoI and DoI support ADR. The term "off diagonal" applies to approaches that are, for some reason, thought to be unbalanced (e.g. where individuals or entities have decision rights but do not have the access to others or to information they need to properly exercise those rights.

C2 AGILITY

The ability of an Entity to successfully accomplish the functions associated with C2 given an Endeavour Space. C2 Agility is a function of both the Agility of the C2 Approaches and C2 Maneuver Agility.

C2 APPROACH AGILITY

The Agility of a particular approach to C2 (e.g. de-conflicted, coordinated, collaborative, edge) is related to the size and location of the region(s) in Endeavour Space where an Entity, employing this particular approach to C2, can successfully operate.

C2 MANEUVERABILITY (ALSO REFERRED TO AS C2 MANEUVER AGILITY)

The ability of an Entity to appropriately change its position in the C2 approach Space (approach to C2) as the mission or task and/or circumstances change.

C2 MATURITY

The SAS-085 NEC C2 Maturity Model defines five levels of C2 Agility.

Figure 21. C2 Maturity Levels and C2 Agility

C2 Agility

C2 Maturity Levels	Contents of C2 Toolkit	C2 Approach Decision Requirement	Transition Requirements
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	Recognise 3 situations and match to appropriate C2 approach	Collaborative C2 Coordinated C2 De-Conflicted C2
Level 3	Coordinated C2 De-Conflicted C2	Recognise 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

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COMPLEXITY

A characteristic of systems with higher-level behaviors characterized by interactions among entities; such higher-level behaviors may be quite unlike those of individual entities and may be described as "emergent" properties of the whole rather than its parts (Example: the ferocity and momentum of a massed army emerges from both individual-level characteristics and the army-wide coherence achieved by leadership, organization, and training.). One important characteristic of many complex systems is that, in some circumstances, their behaviors are extremely sensitive to small changes of condition—so much so as to make their behaviors unpredictable in such circumstances. Dealing with complex systems is in part a matter of recognizing such circumstances, and employing one's Agility.[110]

[110] Complexity science, or the science of complex adaptive systems, has been heavily researched over the last two to three decades. Some standard sources include John H. Holland and Heather Mimnaugh (1996), H*idden Order: How Adaptation Builds Complexity* (New York: Perseus) and Yaneer Bar-Yam (2003), Dynamics of Complex Systems, Westview Press.

COMPLEX ENTERPRISE

Complex endeavors are characterized by both the nature of the collection of participants who are working toward a shared purpose(s) and the nature of the effects of interest. Specifically, the participants consist of a large number of disparate Entities that include not only various militaries but also civil authorities, multinational and international organizations, non-governmental organizations, companies, and private volunteer organizations. The effects of interest go far beyond military effects to include social, political, and economic effects. In reality, the participants do not in fact completely share values or an objective function. However, the participation of individual Entities reflects the fact that participation and/or the projected outcomes associated with the endeavor have value for them. The nature of the participants makes the Collective action space complex while the multi-domain effects space contains complex interactions among effects of various types. In addition, the relationships between the action and effects spaces further contribute to the complexity of the endeavor. (Alberts and Hayes, Planning: Complex Endeavours 2007)

DISTRIBUTION OF INFORMATION (DOI) (AN ENABLER OF AGILITY)

The distribution of information across participating Entities refers to the extent to which the information needed to adequately accomplish required tasks is available to each participant (SAS-065, 2010)

ENDEAVOUR SPACE

A space of possible situations characterized by the following dimensions:

- Effects Space (PMESII, diversity (competency, cultural, values) of Entities)
- Dynamics (time pressure, stability)
- Uncertainty (predictability, familiarity)
- Risk (likelihood, consequences)
- Number of Entities and their relationships
- Cognitive Complexity (smart adversaries, degree of intent)

A given situation corresponds to a point in this space.

FLEXIBILITY

The ability to employ multiple ways to succeed and the capacity to move seamlessly between them (David S. Alberts & Hayes, 2003).

INNOVATIVENESS (AN ENABLER OF AGILITY)

The ability to do new things or the ability to do old things in new ways. (David S. Alberts & Hayes, 2003)

MISSION COMMAND

This term has been used historically to describe command by 'mission orders' where subordinates are given a great deal of discretion in how they accomplish the mission. More recently a white paper, Entitled Mission Command, was issued by the chairmen of the Joint Chiefs of Staff (United States). It calls for, among other things, more adaptive leaders at every level.

NETWORK ENABLED C2

The term "Network Enabled" replaces the earlier "Network Centric", and refers to approaches to C2 that attempt to leverage the shared awareness achieved as a result of widely spread sharing of information enabled by networks, both social and technical, that are enabled communication and information technologies.

PATTERNS OF INTERACTION (POI)

Patterns of interaction between and among participating Entities are a function of their respective abilities and willingness to interact as well as the opportunities they have as a result of the actual occurrence of interactions and collaborations. Interactions are enabled and their quality is enhanced by the ability to have (face-to-face or virtual) meetings, the connectivity of the infostructure, and the degree of interoperability that exists between and among a set of participants (technical, semantic, and cooperability) (SAS-065, 2010)

RESILIENCE (AN ENABLER OF AGILITY)

The ability to recover from or adjust to misfortune, damage, or a destabilizing perturbation in the environment. . (David S. Alberts & Hayes, 2003)

RESPONSIVENESS (AN ENABLER OF AGILITY)

The ability to react to a change in the environment in a timely manner (David S. Alberts & Hayes, 2003)

REQUISITE C2 MATURITY

The level of maturity that is appropriate for an entity given its nature and purpose(s) or for a mission given the circumstances.

REQUISITE C2 AGILITY

The level of C2 Agility that is appropriate for an entity given its nature and purpose(s) or for a mission given the circumstances.

SELF -MONITORING

An executive function where the Collective must monitor and track the *Endeavour Space Complexity* and determine whether their *Actual C2 Approach* matches the *Appropriate or Required C2 Approach*. If not, the Collective must take the appropriate steps to change their *Actual ADR*, *DoI*, and *PoI* to match the *Required ADR*, *DoI*, and *PoI*.

VERSATILITY (AN ENABLER OF AGILITY) (FORMERLY ROBUSTNESS NATO SAS-065)

The ability to maintain effectiveness across a range of tasks, situations, and conditions (David S. Alberts & Hayes, 2003). The term is used to refer to a passive quality and, when applied to an approach to C2, refers to the Agility of a C2 Approach or C2 Approach Agility.

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Annexes

ANNEX A: HETEROGENEOUS C2: WHEN THE "C2 APPROACH" REQUIRES MANY C2 APPROACHES

ANNEX B: SAS-085 CASE STUDIES

ANNEX C: OVERVIEW OF UK C2 AGILITY WORK

Command and Control (C2) Agility

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