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International Multi-Experimentation Analysis on C2 Agility

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Abstract

Agility is being increasingly recognized as an important capability of modern military organizations, one that will enable them to successfully cope with complexity and uncertainty. C2 Agility is a critical enabler of force agility. NATO SAS-085 has been established to better understand C2 Agility and build a conceptual model facilitating experimentation and operationalization. A core hypothesis is that more network-enabled C2 approaches exhibit more *Agility* than less network-enabled approaches. In this paper, we present results from experiments conducted under the aegis of the SAS-085 to sustain (or disprove) this hypothesis. Starting with a common conceptual framework (based on the Network Centric Warfare theory and the NATO Network Enabled Capability (NEC) C2 Maturity model), the experiments were conducted by different organizations and researchers (from Canada, Italy, Portugal, UK and USA) using different experimentation platforms (i.e., agent-based ELICIT, IMAGE, PANOPEA and WISE), measures of effectiveness, and endeavor spaces. Findings, analysis and results of this integrated set of experiments and the conclusions drawn from this international effort.

1 Introduction

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. To enable NATO to better meet these complex mission challenges, NATO adopted the development of Network Enabled Capability (NEC) as a high priority alliance goal, identifying a series of NEC levels that represented progressively more mature capability. A critical component of NEC is Network Enabled Command and Control (NEC2). In 2006, the NATO Research and Technology Organisation (RTO), under the auspices of its System Analysis and Studies (SAS) Panel, chartered a research group, SAS-065, to identify and explore the nature and potential effectiveness of a set of NEC C2 Approach options that would correspond to each of the four NATO NEC capability levels[1].

Early in their efforts to identify and assess a set of networked enabled C2 approaches, SAS-065 came to the conclusion that "Two key realities dominate thinking about command and control (C2) in the 21st century. The first is the nature of the 21st century military mission space. This space is characterized by its extreme uncertainty. In addition to the high intensity combat operations that are traditionally associated with military operations, the 21st century mission space has expanded to include a wide spectrum of mission challenges, ranging from providing support to multi-agency disaster relief operations to complex coalition efforts within a political-military environment involving a large variety of military and non-military actors; which we describe as Complex Endeavors. The second reality is the ongoing transformation of 21st century militaries, and for that matter, other 21st century institutions and actors, from the Industrial Age to the Information Age. With this transformation comes the ability to leverage new information technologies. This has had, and will continue to have a profound effect on how institutions manage themselves and how they can work with coalition partners. These fundamental realities put the emphasis on C2, interpreted in its broadest sense to include acquiring, managing, sharing and exploiting information, and supporting individual and collective decision-making."[2]

Complex Endeavors present a level of difficulty that is qualitatively different from traditional missions. This degree of difficulty can be traced to significantly heightened levels of uncertainly, risk, and time pressure[3] that are a direct result of both the mission complexity and dynamics and the operating environment and/or the complexity of the "organization" or collective that is required to prosecute the mission or accomplish the tasks under the circumstances present. Challenges that rise to Complex Endeavors require "Complex Enterprises[4]" that are not amenable to traditional approaches to command and control, management or governance. This is because these traditional approaches to command and control are based upon a set of assumptions that while appropriate for industrial age organizations, do not necessarily hold for the Complex Enterprises associated with Complex Endeavors.

SAS-065 recognized that approaches to command and control (C2 Approach options) need to be viewed from two perspectives: first, from the familiar perspective of the individual entity; and second, from the perspective of a collective, an assemblage of a large number of independent, yet interdependent entities. Thus, it was critical to develop a better understanding of the appropriateness of different entity and collective approaches to C2 and the ways in which each impacts the overall effectiveness of both individual entities and the Collective. The thinking about C2 has almost exclusively focused on a single entity. Thus, the biggest gap in our understanding involves the C2 of a collection of independent, yet inter-dependent entities that have not entered into a "union" that creates an integrated entity. Accordingly, "SAS-065 concentrated its attention on the second perspective to address C2 for a collective or ad hoc coalition, based upon variations in the allocation of decision

[1] NATO defined a set of capability levels that included de-conflicted, coordinated, collaborative and coherent see http://www.dodccrp.org/files/nnec_fs_executive_summary_2.0_nu.pdf
[2] NATO NEC C2 Maturity Model, Executive Summary (Alberts, Huber, & Moffat, 2010)
[3] Alberts, D. S. The Agility Advantage: Survival Guide for Complex Enterprises and Endeavors, DoD CCRP Publications, 2011 Chapter 3
[4] A Complex Enterprise is an entity or collection of entities that have the characteristics identified in the definition of Complex Endeavors.

rights to the collective, patterns of interactions and information sharing behaviors among the entities of the collective, and the distribution of information among these entities."[5]

SAS-065 found that the effectiveness of a Complex Endeavor depended upon the appropriateness of the C2 Approach employed by the Collective; that more network enabled C2 approaches were needed for the most challenging (dynamic and complex) missions; and that indeed, more network-enabled C2 approaches were sometimes adopted or evolved in the cases studied. The lack of success observed in particular endeavors was attributed to an inability to adopt an appropriate approach (in all cases a more network-enabled approach) to Collective C2. The inability to adopt an appropriate approach in turn was traced to a lack of trust, interoperability, information sharing, collaboration mechanisms, and culture differences, 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 approach that was situation appropriate at some point in time, as no longer appropriate, and 3) no other approach options were available even though it was recognized that there were problems with the approach. This led SAS-065 to the conclusion that having more than one approach option in an entity's tool kit coupled with an ability to understand the conditions and circumstances where each was appropriate (or inappropriate) to achieving success and having the ability to transition to an appropriate approach was related to C2 Agility. Thus, C2 Agility was thought to be a requirement for Complex Endeavors.

SAS-085 on C2 Agility and Requisite Maturity took over where SAS-065 left off with a charter to further explore the concept of C2 Agility and provide answers to the following questions:

- What do we mean by Agility / C2 Agility?
- How can one measure Agility / C2 Agility?
- To what extent is C2 Agility a requirement for Complex Endeavors / Enterprises?
- What are the enablers / inhibitors of C2 Agility?
- Are more networked enabled approaches to C2 more agile?
- How can one move C2 Agility from a theory to become an institutionalized practice?

In order to seek and provide answers to these questions, SAS-085 designed and conducted a set of case studies and experiments. This paper presents the findings of a prospective meta-analysis of the results of these experiments that addresses the relationship between C2 Approach, a measure of effectiveness and agility. The C2 approaches considered were the set described by NATO SAS-065 in the NATO NEC C2 Maturity Model (Alberts, Huber, & Moffat, 2010). The first section of this paper introduces previous similar work. Section 3 is devoted to the experimental design. Section 4 presents the results of the analysis pertaining to each hypothesis. This paper concludes with discussions, recommendations, and future work.

2 Background

This paper builds upon and extends previous analyses of the relationships between and among C2 Approach, effectiveness, and agility. "The Agility Advantage" (Alberts, 2011) introduces Agility Maps and metrics and, using the ELICIT environment, instantiates different NATO NEC C2 approaches to explore the relationships among effectiveness, efficiency and agility. "Operationalizing and Improving C2 Agility: Lessons from Experimentation", (Alberts & Manso, 2012) reviews the existing conceptual and theoretical foundation consisting of the NATO NEC C2 Maturity Model, C2 Agility Conceptual Model, Agility metrics, and a measurement process, and, based on experimentation results, determines that these enable us to systematically explore C2 agility-related hypotheses and improve the practice of C2. Several papers present the results of C2 Agility-related case studies and experiments. In "Agility of C2 Approaches and Requisite Maturity in a

[5] NATO NEC C2 Maturity model Executive Summary page xvii

Comprehensive Approach Context" (Bernier, 2012), a simulation model implemented in IMAGE was used to explore 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.

However, each of these contributions was based upon a single experimental environment. SAS-085, in order to see if the results of individual experiments held more generally, designed and conducted experiments that employ multiple experimental environments, simulation models, and scenarios that utilize different measures of effectiveness, different definitions of success and different endeavor spaces.

3 Experimental Design

In order to produce a more complete, robust and generalizable set of findings SAS-085 undertook a prospective meta-analysis based on a common high-level experimentation design utilizing multiple experimental platforms and venues. Specifically, SAS-085 members from five NATO member nations, namely USA, Portugal, Canada, United-Kingdom, and Italy jointly conceived and conducted a series of experiments. Together they defined a set of common research hypotheses and identified comparable independent and dependent variables. Bernier et al. (2013) presents the methodology and discusses the challenges of such meta-analysis. The individual experiments did not conducted the analysis themselves but instead reported all data into single compendium to be analysed jointly in the meta-analysis.

3.1 Hypotheses

An important objective of the meta-analysis was to assess the effect of adopting one or many C2 approaches on agility, i.e. on the ability to successfully cope with a more or less significant portion of the endeavor space. This paper covers two hypotheses related to this objective:

- H1: Entities operating with more network-enabled C2 approaches exhibit more agility
- H2: Entities that have a more mature C2 capability are potentially more agile

Another paper treats (Bernier, Chan, Alberts, & Pearce, 2013) with three complementary hypotheses that, among other things, investigate possible explanations of the results presented in the current paper.

3.2 Design

Figure 1 illustrates a schema of the experimental design that involves two explicit independent variables and one implicit independent variable. The first independent variable, *C2 Approach*, can take on five different values (Conflicted, De-Conflicted, Coordinated, Collaborative, or Edge). A single experiment instantiates from two to all five of the pre-defined C2 approaches. Verifications were made to ensure that these C2 approaches were equivalent across all experiments. The second independent variable, *Endeavor Space* represents a series of challenges and conditions, each of which could occur in any given C2 Approach. Each experiment employed a different endeavor space. Finally, *Experiment* is an implicit independent variable. It is of little interest in itself but is nevertheless captured because it represents a sample of a virtually infinite population of experiments that do not all exist yet but that could be created with the same purpose as this experimentation. This way, findings with these six experiments can be generalized to an infinite number of experiments that could be created in a similar fashion and for the kind of studies. The six experiments were IMAGE (Lizotte, Bernier, Mokhtari, & Boivin, 2013), WISE (Pearce, Robinson, & Wright, 2003), PANOPEA (Bruzzone, Tremori, & Merkuryev, 2011) and three variants of ELICIT (Alberts, 2011; Chan & Adali, 2012; Manso, 2012).

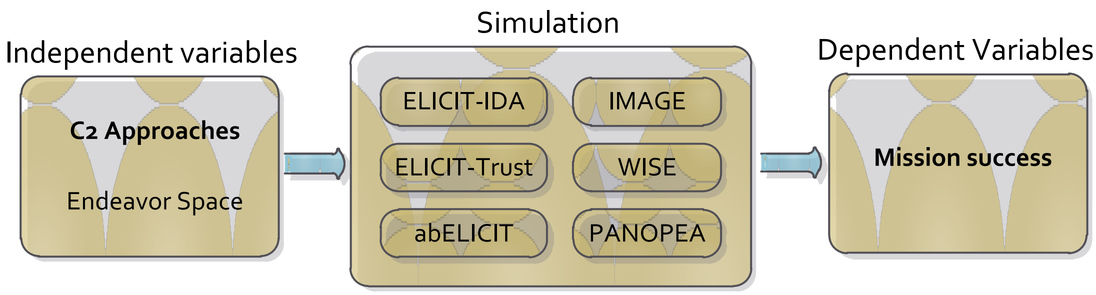

Figure 1: Experimental design.

Each experiment defines a unique endeavor space that comprises up to 100 challenges, also called Changes in Circumstances (CiCs). Some CiCs represent degraded/extreme environments or various degrees of situational complexity or dynamics, situations that a collective may have to overcome to succeed in its mission. The primary role of the endeavor space is to deduce agility via the agility score, i.e. the proportion of the endeavor space where a collective is successful. But it serves two additional purposes. First, the endeavor space corresponds to what is called a *noise factor* in the literature (Steinberg & Bursztyn, 1998). Such factors aim at recreating the natural variability found in the real-world and then at improving the external validity and robustness of the findings. Second, incorporating a large quantity of CiCs reduces the probability of selecting only CiCs that would be systematically detrimental or beneficial to some C2 approaches (law of large numbers). Between two and five types of CiCs were included for each experiment. The resulting endeavor spaces was then populated by performing all possible combinations of the possible values (e.g. low/high latency x low/high trust) for all these types of CiCs.

Simulation runs were performed for every combination of the independent variables *CiC* (4 to 108 instances per experiment) and *C2 approach* (2 to 5 instances per experiment), for a total of 908 combinations. Since the endeavor space and then the CiCs are unique to each experiment, *CiC* is a variable nested within *Experiment*. The only dependent variable measured for each run that is relevant for this paper is the normalized value representing the success or failure of the mission. The agility of a collective operating under a given C2 approach was then measured by the proportion of the endeavor space (or CiCs) in which a collective is successful. This value is called the *Agility Score* and is calculated by averaging all values of *Mission Success* measured for all CiCs simulated for a given C2 approach.

A meta-analysis exploits blocking in its design. Each *Experiment* is a block of homogenous experimental units; dependent variables are more alike within an experiment than among experiments, that is, values within an experiment are not independent of each other. Consequently, the hypotheses were tested with an analysis of variance using a mixed effect model for which *Experiment* was the random variable and *C2 Approach* the fixed effect. To reiterate, a set of simulation runs were conducted by each nation according to a common experimental plan. Then, these data were merged in the meta-analysis. Its main results are presented next.

4 Results

4.1 C2 Approach Agility

Since agility is the capability to successfully cope with circumstances, it is always relative to a specific Endeavor Space. The dimensions of an endeavor 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 endeavor space that we referred to as a CiC[6]. Agility maps are graphical representations of the success of failure of a collective employing one or more approaches to C2. They portray the regions (collections of points or cells) in the endeavor space where each C2 approach is successful.

[6] Since, by definition Agility does not apply to a static situation the endeavor space of interest contains all of the possible ways a situation could change. Some researchers include a baseline (current or expected situation) in the form of a cell or point in Endeavor Space.

Since endeavor spaces can easily consist of more than two dimensions, thus 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 its two dimensions (x and y axes), meaning that some variables are nested within others. In each of these Experiments, simulation runs were made for each instantiated C2 approach under every possible combination of endeavor space variables. Thus, the resulting Experiment 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 a CiC. The value obtained for the measure of success for each CiC is one for a collective employing a given C2 approach.

Figure 2 illustrates the agility map corresponding to each Experiment. Values of mission success were binary in the case of IMAGE (1=success, 0=failure) while they were continuous (between zero and one) for the other experiments because each measure of success represents the average to many replications or the measure was an average value. Higher levels of mission success correspond to darker shades of teal while only the lighter shade of teal means failure. Blank squares represent non-simulated cases because the C2 approach was not implemented by the Experiment. The endeavor spaces were organized such that the less challenging CiCs were placed closer to the bottom left-hand corner while the most challenging CiCs were closer to the top right-hand corner with a qualitative gradation of difficulty when moving from one corner to the other.

Agility score was calculated for each C2 approach and each experiment (see Table 1). Note that for every Experiment more network-enabled C2 approaches generated higher agility score. A statistical test was conducted to assess H1: Do collectives operating with more network-enabled C2 approaches exhibit more agility? The effect of *C2 approach* on *Agility score* was modeled by a linear mixed model with *C2 approach* as fixed effect and *Experiment* as a random effect in order to control for the specific scale of agility score of each experiment (effect of blocking explained earlier).

Table 1: Agility scores for each C2 approach and experiments – least square means (M) and standard error (SE).

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)

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 Table 2). The two most network-enabled C2 approaches (Edge, Collaborative) demonstrated significantly more agility than the three less network-enabled C2 approaches. Small "increments" for less network-enabled C2 approaches (e.g. from De-Conflicted vs. Coordinated) were not sufficient to observe a significant improvement in agility.

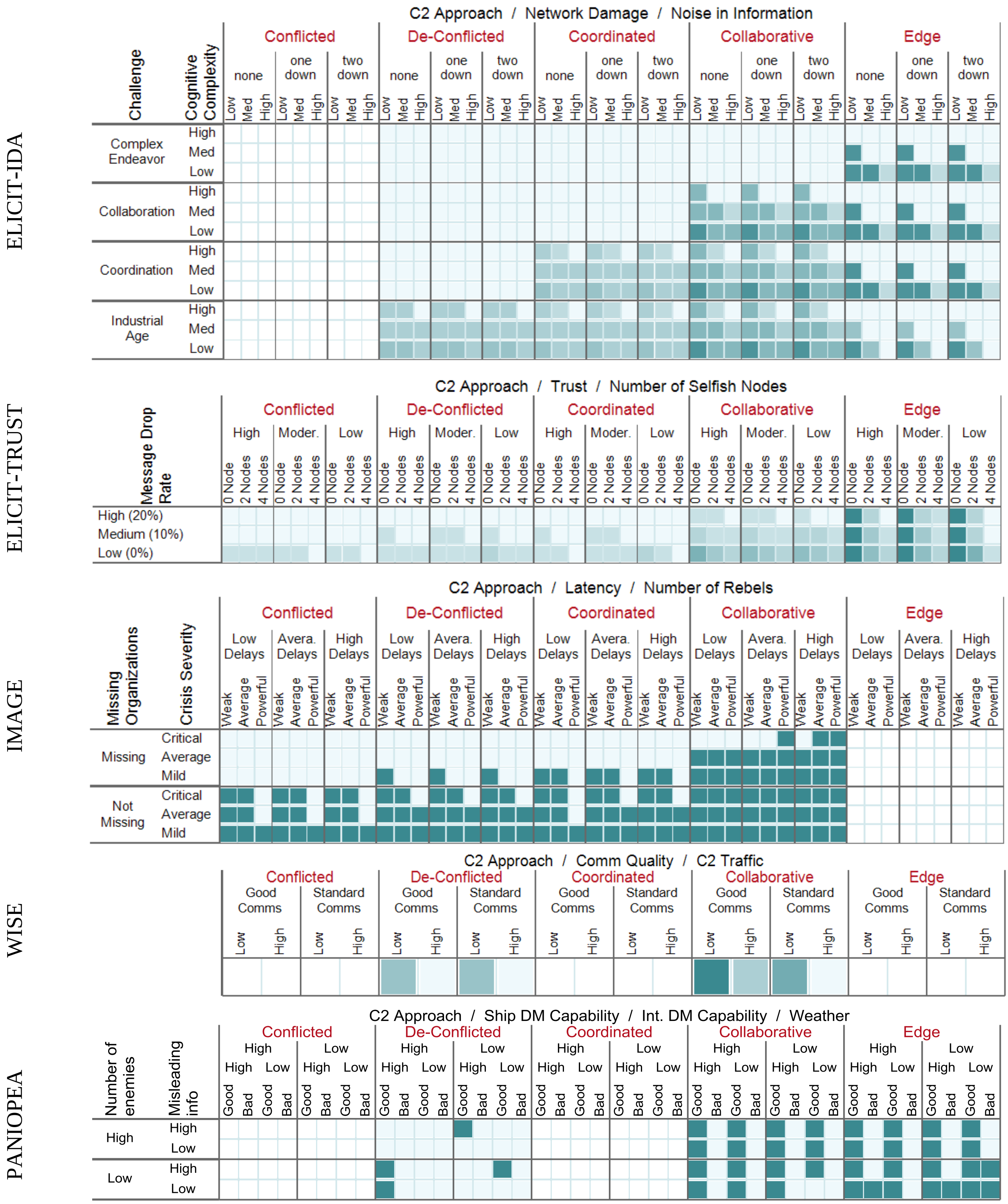

Figure 2: Agility maps.

Table 2: Estimated agility score changes (and standard error) for each pairwise comparison of C2 approaches.

	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 < 0.001

Results strongly support the first hypothesis. In addition to test a specific set of hypotheses, simulation-based experiments usually present unexpected findings and incoherencies, both of which suggest future research. These benefits of experiments are often difficult to identify when only developing theories or conducting case studies without quantitative data. The following observation is an example of such finding. Figure 3 shows the progression of agility scores as an organizations move from a given C2 approach to a more network-enabled one. Assuming that C2 approaches are equally distant from each other on a "C2 approach scale", the relationship between C2 approach and agility score obeys to a quadratic relationship with a correlation coefficient of 0.99[7]. Such results suggest that agility gains are non-linear and that they accelerate when moving toward more network-enabled C2 approaches. Is there an underlying reason that makes this relationship quadratic? A mediator variable[8] is a possible explanation. The most likely variable that could play this role is the position in the C2 Approach Space. Another paper (Bernier, Chan, et al., 2013) looking at these results looks at the role of this potential mediator variable.

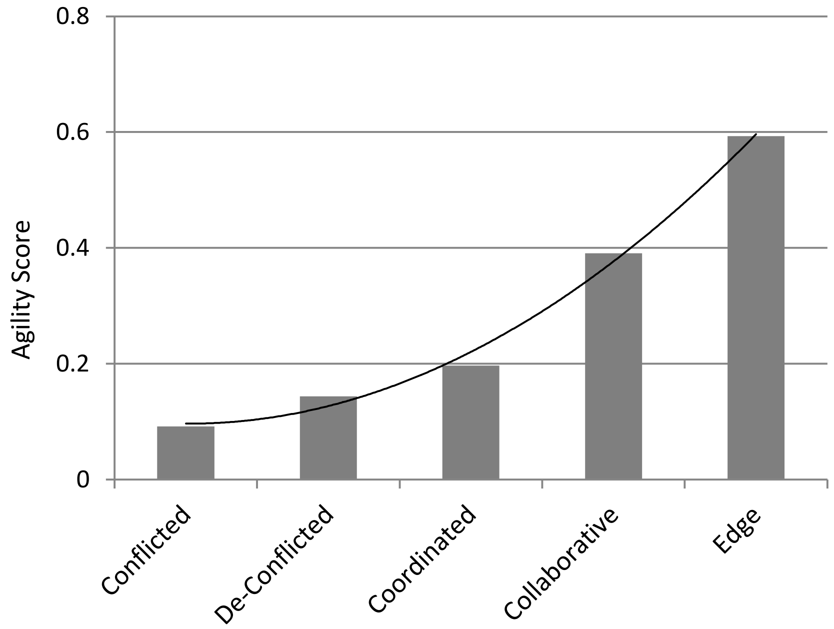

Figure 3: Average (LS-Mean) agility scores calculated from the six experiments.

[7] Fitting five points with a quadratic equation that comprises three degrees of liberty will certainly result in high coefficient of correlation but still, 0.99 is quite a high number even in this context.
[8] 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 (e.g. *C2 Approach*) and a dependent variable (e.g. *Agility Score*).

4.2 C2 Agility

Even if collectives operating in more network-enabled C2 approaches are more agile, there are some situations (CiCs) 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 endeavor 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, in some situations are considerations may favor the adoption of less network-enabled C2 approaches.

Figure 4 illustrates the most successful C2 Approach for coping with each CiC and across each experiment. In case where more than one C2 Approach was equally effective, the least network-enabled C2 Approach was selected. Although Collaborative and Edge can better cope with more challenging CiCs, other C2 approaches are potentially more cost-effective solutions for many less, but still challenging, CiCs. It is easy to wrongly interpret this figure because it does not show if the second (or the third) best performing C2 Approach (can be either almost as good as the best one. A more detailed graphical representation would need to be used to show the stacked squares (ones underneath the one shown) hidden in this figure.

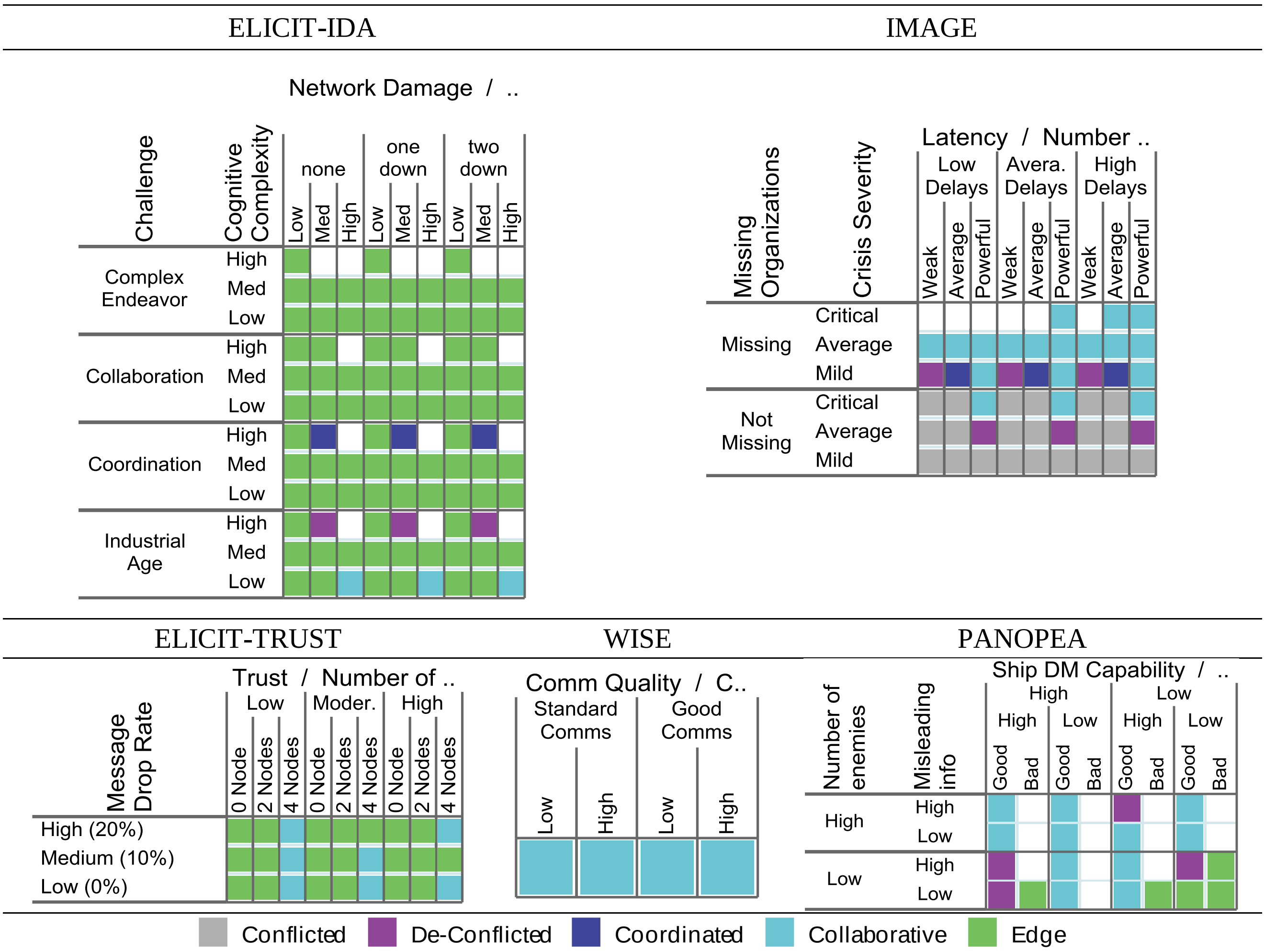

Figure 4: Map of the most successful C2 Approach for each CiC.

The proportion of the endeavor space where a given C2 Approach is as good as or better than other C2 approaches was calculated (see Table 3). Even if Edge takes the lion's share, some C2 approaches also perform quite well. Values corresponding to Conflicted are probably over estimated because of one experiment (IMAGE). The standard deviation highlights this fact.

Table 3: Proportion of the endeavor space where a C2 Approach is the most (or equally) successful one (less network-enabled C2 Approach favored when tied).

C2 Approach	ELICIT-IDA	ELICIT-TRUST	IMAGE	WISE	PANOPEA	Average
Conflicted		0.00	0.40			0.20 (0.18)
De-Conflicted	0.03	0.00	0.11	0.00	0.13	0.05 (0.12)
Coordinated	0.03	0.00	0.06			0.03 (0.15)
Collaborative	0.03	0.26	0.34	1.00	0.35	0.39 (0.12)
Edge	0.78	0.74			0.16	0.56 (0.15)

Entities that are able to adopt more than one C2 Approach should be successful in a greater portion of the endeavor space than entities that can only adopt a single C2 Approach, even if it is the most agile of the C2 approaches instantiated in this series of experiments. C2 Agility depends on the agility provided by each C2 an entity can adopt and of the ability of this entity to efficiently adopt (maneuver) different C2 approaches according to the circumstances. Maneuver Agility is defined by SAS-085 as the ability to 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.

A realistic experiment on C2 Agility would incorporate the imperfect processes that monitors the situation, detects (or anticipates) the point in endeavor space that represents the situation (CiCs), 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 included a capability to transition from one approach to another, it is possible to calculate the resulting agility provided by a collective able to support more than one C2 Approach under close to ideal conditions to serve as a measure of the potential value of C2 agility. This calculation involves selecting the best C2 Approach given each circumstance (CiC). This method is equivalent to setting the costs of transition and the delays involved to zero, that is it assumes a close to perfect Maneuver Agility. The value obtained is close to the maximum Maneuver Agility possible given the endeavor space and the set of C2 Approach options available. Close to and not actually the maximum because this calculation does not include the benefit of anticipating CiCs, i.e. it does not implement the proactive monitoring that exploits weak signals (Hollnagel, Woods, & Leveson, 2006) announcing CiCs in order initiate a change before being fully impacted by a CiC (which is the case here).

C2 Maturity Levels are groups of C2 approaches a collective supports and can choose among. 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 portion of the endeavor space where a collective can be successful were calculated for each C2 Maturity Level and each Experiment (see Table 4). These values were not computed from the proportion of CiCs corresponding to best/good enough C2 approaches (data corresponding to Figure 4) that would be part of a given maturity level. Instead, these values were calculated by selecting the highest mission success value among the C2 approaches comprised in a given maturity level. In addition, assuming that collective with more mature C2 would be better at pre-emptively/early transitioning between C2 approaches, the values computed here probably underestimated the agility scores for the higher levels of C2 Maturity.

Statistical tests were conducted for verifying if higher levels of C2 Maturity provide more agility than the lowest levels. Stated otherwise, does increasing C2 Maturity improve the agility of a collective? As in the previous examples, the effect of *C2 Approach* on *Agility score* was modeled by a linear mixed model with a random *Experiment* effect.

Table 4: Agility scores according to C2 Maturity Levels.

Maturity Level	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)

There was a significant effect $F(4,8) = 11.19$, $p < .001$ for the level, 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 10 paired comparisons were significant: both Level 4 and 5 resulted in significantly more agility than Level 1, 2 or 3. Results are quite similar to those obtained when comparing the agility scores corresponding to each of the C2 approaches. In fact, the results are so similar that it raises another question. Does the agility of a given level of C2 Maturity comes from ability to switch from one C2 Approach to another or simply from the more network-enabled C2 Approach(es) that it includes? Table 5 shows the difference in agility scores corresponding to a given C2 Maturity level and to the more network-enabled C2 approaches a maturity level includes.

Table 5: Difference of agility scores between C2 Maturity levels and the most network-enabled approaches they include.

Comparison	ELICIT-IDA	ELICIT-TRUST	IMAGE	WISE	PANOPEA	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)

At first sights the differences are small. A paired samples t-test confirmed that the difference of agility scores (M = .003) is statistically different from zero, $t(17) = 2.44$, $p = .01$, but a difference of 0.3% of the endeavor space represents a small benefit.

The meta-analysis of the results that C2 agility is likely to be interesting from a cost-effectiveness perspective, but entities would gain little additional agility when compared to adopting the most network-enabled C2 Approach for a given C2 Maturity level. This finding seems to call into question the conclusion of SAS-065, which claims that more mature C2 approaches are more agile. The problem arises from the basis of the comparison. If the comparison is between two levels of C2 Maturity, then yes the hypothesis is validated. But if the comparison is between the most network-enabled C2 Approach a level includes and having a choice among all of the C2 approaches included, then the difference is statistically significant but it may not be significant in practice.

One explanation for the small difference revealed by this last test is the incomplete/deficient selection of the CiCs populating the endeavor space tested in the experiment. Since many CiCs chosen for this experiment 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 CiCs if it already succeeds against the most challenging one. Consequently, the endeavor space is populated mainly by quantitatively rather than by qualitatively different CiCs, but the latter is where agility manifests its benefits. Future experiments should try to create as varied endeavor space as possible thus incorporating more diverse CiCs. Another reason 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 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, there are a number of aspects to be considered when conducting future research.

5 Conclusions

In the last decade, the military organizations of NATO nations have faced challenges of a qualitatively different nature than they did when NATO was formed. These include operations with increased complexity and tempo, diffuse enemies, and extreme uncertainty. Traditional C2 approaches are not well-adapted to this new reality. The Network Enabled Operations (NEC) C2 Maturity Model (N2C2M2) describes five C2 approaches that correspond to different ways to accomplish C2 functions. When looking at how to employ C2 approaches in a complex endeavor, three implicit assumptions need to be carefully reviewed. First, the presumption that the most network-enabled C2 Approach possible is always the best. Second, more network-enabled C2 approaches are likely to better perform over a broader range of challenges. Finally, military organizations that efficiently employ more than one approach (i.e. that are C2 agile) should be in better position to successfully cope with a larger spectrum of conflicts and situations, including the unexpected ones.

Two main hypotheses were investigated in this paper. First, entities operating with more network-enabled C2 approaches exhibit more agility. Second, entities that have a more mature C2 capability (i.e. that can adopt more than one C2 Approach) are potentially more agile. The meta-analysis that assessed these hypotheses was based on six different experiments, each of which was designed for the purpose of studying C2 approaches in contexts characterized by complex endeavors.

The results of this meta-analysis largely confirm the first hypothesis, namely that when comparing all pairs of C2 approaches (i.e. a pair compares a more a network-enabled C2 Approach with a less network-enabled one), 7 out of 10 possible pairs are to the advantage of the more network-enabled C2 Approach. As for the three others pairs (De-Conflicted vs. Conflicted, Coordinated vs. Conflicted, Coordinated vs. De-Conflicted), the advantage is still for the more network-enabled one but the statistical test is not significant because the difference between those approaches is not large enough. This observation leads to the second findings: the ability to successfully cope with the endeavor space does not increase linearly as a collective adopts a more network-enabled C2 Approach. The relation is quadratic. This result suggests a mediator variable with a quadratic effect on agility. It was suggested that the current position of a collective in the C2 Approach Space may be that variable and is investigated in a co-paper on the same experiment (Bernier, Chan, et al., 2013). Another paper (Alberts, Bernier, Chan, & Manso, 2013) also explores the location in the C2 Approach Space but for ELICIT only.

The results of the test for the second hypothesis were less convincing than what was expected. As anticipated, some portions of the endeavor space were successfully handled by less network-enabled C2 approaches like Conflicted, De-Conflicted and Coordinated. Another test showed that collectives that adopt higher levels of C2 Maturity are more agile. However, the results of this test were suspiciously similar to those of the first hypothesis, which suggests that the agility of a given level of maturity may derive mainly from the most network-enabled C2 Approach that such a maturity level includes. An additional test confirmed this. In summary, the analysis conducted by SAS-085 showed that C2 agility is likely to be interesting from a cost-effectiveness perspective, but according to the limited experiments conducted, entities stand to gain little additional agility when compared to simply adopting the most network-enabled C2 Approach they can. A few plausible reasons explain this result and future work is needed to employ this finding.

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