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Agility of C2 Approaches and Requisite Maturity in a Comprehensive Approach Context

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Abstract

Agility has recently caught the military community's attention as a possible contender to deal with complex endeavours. Many enablers of agility have been identified but several aspects of their implementation are not completely understood. The Network Enabled Operations (NEC) C2 Maturity Model (N2C2M2) describes five C2 approaches that correspond to different ways to accomplish C2 functions. It is believed that more capable C2 approaches and higher level of maturity should provide more agility. This paper describes a simulation-based experiment that investigated how C2 approaches deployed in a comprehensive approach context impact agility and mission effectiveness. Comprehensive and whole-of-government approaches are particularly well suited for this study since their success depends on effective coordination between organizations. Results of the simulation suggest that more capable C2 approaches provide more agility. In addition, it suggests that enablers of agility, namely responsiveness, resiliency, flexibility, and situational awareness for this study, are positively correlated with measures of agility.

1 Introduction

Recent crises, especially those arising in fragile states, are characterized by a combination of intermingled and interdependent elements related to security, economic, diplomatic, and humanitarian domains. Recent history showed that such complex endeavours (Alberts, Huber, & Moffat, 2010) can hardly be resolved by military interventions alone. The military community recognized the need to better coordinate with other actors and to tackle the problem in a more holistic way. The comprehensive approach (Leslie, Gizewki, & Rostek, 2008; Spoelstra, van Bemmel, & Eikelboom, 2010; United Kingdom: Ministry of Defence, 2006) and similarly the "whole-of-government" approach (OECD, 2006) aim at using a wide range of political, military, and civilian instruments for solving such crises. These two approaches are not sufficient conditions to resolve a crisis. We live in a new age of increased complexity with the consequence that our ability to predict and anticipate future events is reduced (Alberts, 2011). Not only these highly improbable events can have catastrophic consequences, but also their nature is often unpredictable (Taleb, 2007). Guarding against all eventualities that could occur during a crisis is hardly feasible. Agility, which is the ability to adapt to change, is a more realistic alternative. The military (research) community has recently shown an interest in agility but it should be noted that this topic has been studied by the software development community for more than two decades. Likewise, software development is characterized by complexity and many unexpected changes in circumstances (e.g. new needs/requirements added late in the development, new technology, new competitors) that force unanticipated adaptation. Conboy and Fitzgerald (2004) conducted a review on agility and the similarities with the military domain are numerous. Although many solutions have been proposed and implemented to improve agility, much work remains to be done, especially in the military domain. The SAS-085 NATO task group on Command and Control (C2) Agility and Requisite Maturity was created with the objective of improving the understanding of the importance of C2 agility for North Atlantic Treaty Organization (NATO) and its member nations. Work on C2 agility presented in this paper is one of the few experiments conducted by nations that are part of this task group.

The NATO Network Enabled Operations (NEC) C2 Maturity Model (N2C2M2) defines a number of C2 approaches that correspond to various ways to accomplish C2 functions. These approaches differ on at least three aspects: distribution of information among entities, pattern of interaction among entities and allocation of decision rights to the collective aspects. C2 approaches can be represented in a three-dimensional space as illustrated in Figure 1.

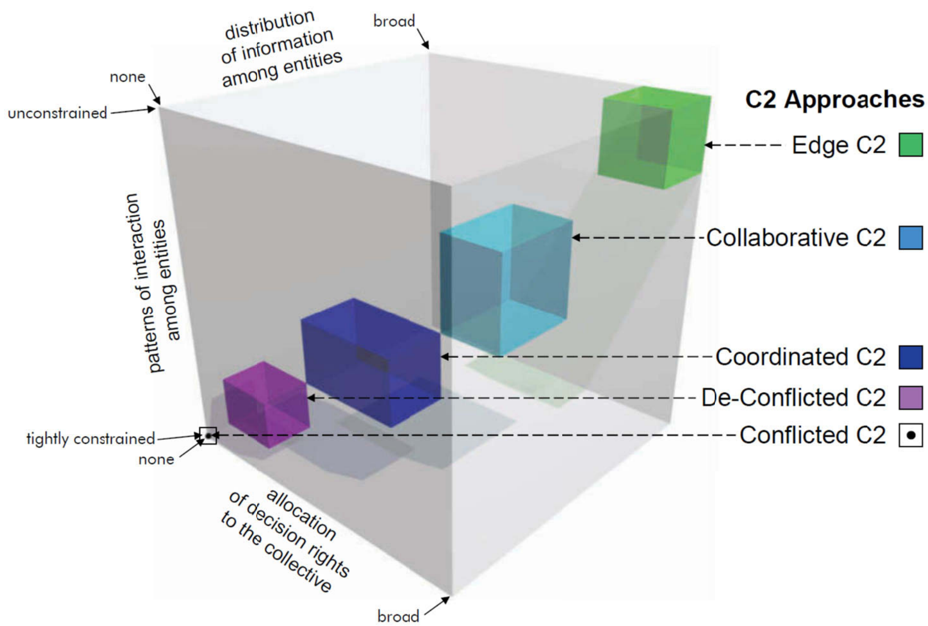


Figure 1: C2 approaches represented in the C2 approaches spaces (from Albert et al. (2010)).

It follows from the definition of the C2 approaches in regard of these three aspects that the more capable C2 approaches should be more effective to solve complex crises and military conflicts. A few simulation-based experiments (Alberts et al., 2010; B. Manso & Manso, 2010; M. Manso, 2010) support this idea. Similarly, more capable C2 approaches should also provide more agility. However, few experiments (Alberts, 2011) assessed C2 agility or the relation between C2 approaches and agility. A small number of simulation-based experiments on C2 approaches applied to "whole-of-government" contexts were conducted (Bigbee, Curtiss, Litwin, & Harkin, 2010; Kott, Hansberger, Waltz, & Corpac, 2010; Powley & Nissen, 2009) with the purpose of getting a better understanding of coordination among organizations and of mission effectiveness but none of them studied agility or N2C2M2. Agility, especially C2 agility or more capable C2 approaches, should help to cope successfully with unexpected events and complex situations but implementing agility in an organization or a collective can be costly. Requisite maturity is a more frugal concept since it refers to the minimal level of maturity required in a given situation. This paper investigates if C2 approaches (as defined in the N2C2M2) applied in a crisis context where a comprehensive approach is relevant would impact agility and mission effectiveness. It also examines the requisite maturity for this context. This paper is organized as follows. Section 2 presents the experimental plan and the hypotheses to be investigated. Section 3 describes the experimental setup, i.e. the simulation model of a comprehensive approach applied to a failing state. Section 4 presents the results of the experiment and Section 5 concludes with a summary and future work.

2 Hypotheses and Experimental Design

The objective of the experiment plan is to understand the effect of each C2 approach on agility and mission effectiveness within complex endeavours. Two hypotheses were tested:

- H1: More capable C2 approaches provide higher level of agility.
- H2: Enablers of agility are positively correlated with measures of agility.

Three independent variables stand out from the hypotheses and the objective: C2 approach, change in circumstances, and level of complexity. The first independent variable—C2 approach—is described and defined in Section 3.5. The second independent variable refers to perturbations that may occur during a mission. These changes are unexpected in time and in their nature. They can occur on the self, i.e. on the systems (people, process, material) an organisation or a collective "owns", or on the environment, i.e. on everything else in the situation like weather, terrain, or enemy. Quantifying the level of expectedness is a controversial task since it involves an element of subjectivity. Instead of using a one-dimensional gradation of changes of circumstances, a simpler and more insightful approach consists in selecting a variety of changes in circumstances in the self and the environment. This approach gives the possibility to nuance the agility according to various types of changes. Four types of changes in circumstances were retained for the experimental plan: two on the self (information sharing delays, missing organizations or not) and two on the environment (enemy strength, crisis amplitude). Finally, one C2 approach may prove to be agile when facing a simple problem but may fail to address very complex “ill-structured” (US Army TRADOC, 2008) or wicked (Kramer, 2010) problems with many intermingled components. The last independent variable, the problem complexity, aims at testing two problem difficulties. More details are provided in Section 3.3. In summary (see Table 1), a full-factorial design resulted in 540 conditions to be tested.

Table 1: Independent variables.

<table>
<tr><th>Factors</th><th colspan="3">Levels</th><th># Conditions</th></tr>
<tr><td>C2 approach</td><td colspan="3">Conflicted, De-conflicted, Coordinated, Collaborative, Edge</td><td>5</td></tr>
<tr><td rowspan="4">Change in circumstances</td><td rowspan="2">Self</td><td>Information sharing delays</td><td>Low, Medium, High</td><td rowspan="4">54</td></tr>
<tr><td>Missing organizations</td><td>Missing (2), Non-missing</td></tr>
<tr><td rowspan="2">Environ ment</td><td>Enemy strength</td><td>Weak, Normal, Powerful</td></tr>
<tr><td>Crisis severity</td><td>Mild, Moderate, Critical</td></tr>
<tr><td>Problem complexity</td><td colspan="3">Low (industrial age) and high (information age)</td><td>2</td></tr>
</table>

As for the dependent variables, the most important one is the measure of mission success. It corresponds to the ability to prevent the failing state government from collapsing. Other dependent variables capture enablers of agility and measures of performance like situational awareness (SA), final score, and responsiveness.

3 Simulation Model

The simulation model was created by using existing simulation models and known modeling approaches and by exploiting real and freely available data of previous multi-agency operations and of an existing fragile state. Despite the fact that the resulting model has never been through a formal verification and validation (V&V) process, it is nevertheless based on reasonable assumptions and previously proven methods. Using real data also provides some protection against the confirmation bias, which is the tendency to find evidences proving our initial hypothesis. In addition, this experiment tries to gain insights on the dynamic of agility for different C2 approaches, not to find the right C2 approach for solving such crises. The model is calibrated to avoid unrealistic ceiling and floor effects which, in turn, ensures sufficient contrast between conditions. The model was implemented in IMAGE (Lizotte, 2008), a suite of representation, "scenarization" (Lizotte & Rioux, 2010), simulation (Rioux, Bernier, & Laurendeau, 2008; Rioux, Laurendeau, & Bernier, 2010) and visualization (Mokhtari et al., 2011; Mokhtari, Boivin, Laurendeau, & Girardin, 2010) tools aiming at improving the understanding of complex situations. Decision-making was implemented using a home-made multi-agent system that conforms to the desire-belief-intention (DBI) paradigm (Ferber, 1999). Section 3 describes the simulation model in sufficient detail for facilitating the interpretation of the results.

3.1 Failing State

The simulation model takes place in the context of a failing state that has experienced years of civil war and conflicts about oil with a neighboring country. The country is afflicted by many problems: lack of infrastructure and education, poverty, flood of refugees, diseases, attacks by rebels, unemployment, and corruption. The international community mobilizes and puts in place a mission involving many organizations that aims at securing and stabilizing the country.

3.2 Multi-Agency Operation

The nature of recent conflicts forces organizations to consider the interdependencies and cross-boundary effects of their activities on other lines of operations. For instance, full-spectrum operations (Chiarelli & Michaelis, 2005) and counterinsurgency doctrine (Petraeus & Mattis, 2006) mention that, for winning the peace, military organizations must not simply focus on military aspects but also consider economic, political, diplomacy, and cultural domains. Consequently, solving modern conflicts and crises involves coordination/collaboration between complementary organizations like military, other government departments (OGDs) and non-government organizations (NGOs). NGOs tackle a similar problem with the cluster approach (McNamara, 2006) that designates a lead agency for each domain of responsibility and enforces collaboration between NGOs in situations involving many entangled components like health, nutrition and protection.

The current simulation model takes from these approaches. It includes a synthetic version of a joint task force, four OGDs, five NGOs, and the police and the armed forces of the failing state. Each organization is specialized in its own sphere of activities like security for military or economic and humanitarian for NGOs. An organization owns between one and six units that execute activities in the country and gather information according to its sphere of activity. As a consequence, each organization has a partial picture and can influence only some aspects of the crisis. A total of 24 units can conduct 39 activities overall. Organizations decide individually or collectively (C2 approach dependent) to whom information must be requested and in which province which unit(s) will perform which activities. The resulting planning process depends on many considerations: avoiding conflicting activities, fostering synergic activities, getting the right information, and moving units to the right province. Activities synchronized in time and space (province) can interact in three ways: independent so the effects of each activity are applied separately (89%), conflicting so that a single or both activities are cancelled (4%), complementary so that an activity ensures the success of another one (2%), and synergic so that the resulting effect is greater than the sum of the individual effects (5%). Humanitarian convoy being protected by armed forces is an example of complementary activities. Leveraging on the logistics of vaccination program for distributing food supplements is one of the many possible synergies. Many of these real world synergies were found on OGDs and NGOs web sites (e.g. www.acdi-cida.gc.ca). Besides being a reality of many recent crises and conflicts, interacting activities permit to assess the impact of various patterns of interactions between organizations. The proportion of each type of interaction was 1) not explicitly chosen but derived from the consideration of each pair of activities and 2) not tested against real data, for such data does not currently exist and may vary from one situation to another.

3.3 Complex Situation

As mentioned previously, irregular warfare and other information age conflicts are complex and many interdependencies arise between all their components (Alberts et al., 2010; Chiarelli & Michaelis, 2005; Kramer, 2010). In comparison, industrial age conflicts were usually more linear, less dynamic, and could be broken into parts to be solved separately since few dependencies existed between their components. A situation with few internal dependencies can be decomposed and each aspect be "solved" separately by highly specialized organizations (e.g. military units for security). Conversely, a situation with many interdependencies requires a holistic approach because problems do not stay confined; they propagate quickly to all dimensions of a crisis. This problem can be mitigated with the comprehensive approach (Leslie et al., 2008) which states that a mission has more chance of succeeding by tackling problems in all line of operations (combat operation, information operations, economic development, essential services, humanitarian aid, governance, etc.). The ability of decomposing or not a problem can be used to change the problem difficulty. It also fosters collaboration between organizations.

The domain of system dynamics has developed many tools to model and study systems characterized by highly interdependent components. Among them, the influence (or impact) matrix, originally developed by Gordon for future forecasting (Gordon, 1994; Gordon & Hayward, 1968) and then adapted by Frederic Vester (1976) for the cybernetic domain, models the interdependencies between events/variables of a system. Kelly and Walker (2004) and Torres and Olaya (2010) have recently applied these approaches of system dynamics to complex problems. The modeling of the influence between variables in the current model is largely inspired by the cross-impact method. A set of normalized variables captures the most important properties of the crisis. Nine variables (*Refugees camp population, Refugees camp security, Refugees camp survivability, Oil extraction, Government support, Health, Food, Agriculture, Security*) pertain to each of the ten provinces while the remaining seven (*Rebel effectiveness, Army effectiveness, Police effectiveness, Economy, Government, International support*) relate to the country itself. Initial values of most variables were based on real data of an existing country for which plenty of documentation and data are available.

For the high complexity version, the influence between each of the 16 by 16 combinations of variables is null in 92 percent of the cases and positive or negative for the remaining 8 percent. Although an activity affects between one or two variables, all other variables are eventually affected through the cross-impact matrix. The variables and the cross-impact matrix were partially based on a previous scenario, created by a SME with extensive military scenario development background, for studying how humans can deal with complex situations (Lafond & DuCharme, 2011). The impact-matrix is empty for the low complexity version. A sensitivity analysis with various cross-impact matrixes (average standard deviation of 0.03 between matrixes for each 16x16 values) resulted in measures of performance with a lower average standard deviation ($\sigma = 0.01$). As for the corresponding measures of success, they varied proportionally with the cross-impact matrix ($\sigma = 0.03$). It follows from this analysis that values in the cross-impact matrix are important but not critical for the validity of the experimental results.

3.4 Simulation Process

The multi-agency intervention is conducted during 31 iterations, a period of time long enough to see the impacts of the changes in circumstances and their resolution. Each iteration is composed of the steps illustrated in Figure 2. The intervention is considered a success if the government variable is not null at the end. Values for dark-green rounded boxes are defined before the simulation begins while values corresponding to other rounded boxes vary during the simulation.

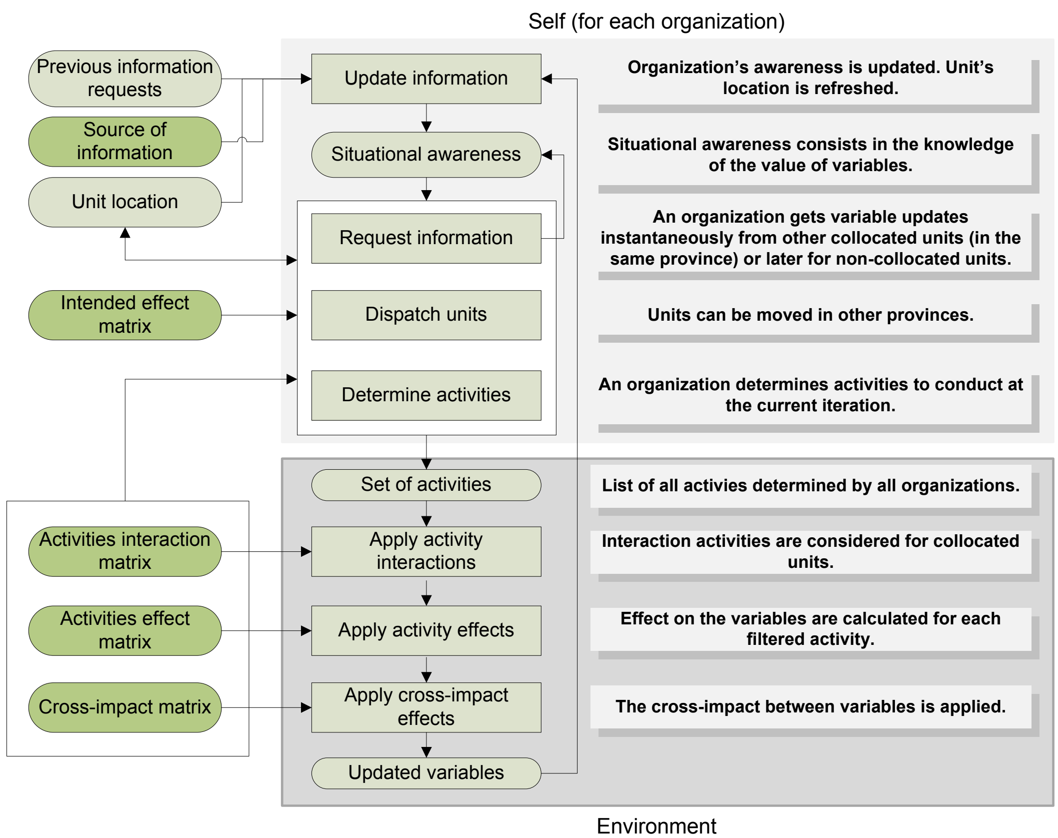


Figure 2: Flow diagram of one iteration of the simulation model.

An iteration is composed of the following steps. First, each organization updates its SA by collecting information (variables) from province(s) where its unit(s) is/are located or from previous information requested from other organizations. Country and province level variables are used to build SA by calculating the absolute difference between values known by an organization and the ground truth. Since the amount of effect that an activity has on variable decreases with its value, organizations should seek variables with the lowest values. Thus, improving SA by moving units to other provinces and exchanging information with other organizations is more likely to augment the chances of success.

Then, an organization asks for information to other organizations having collocated units and to organizations having units in other provinces. This process is instantaneous in the former case and takes a number of iteration(s) that depends on the information sharing quality and the C2 approach in the latter case. Afterward, an organization can relocate some units in other provinces. Finally, activities for the current iteration are chosen. The five C2 approaches were implemented by parameterizing the first four steps which represent the self (see Section 3.5).

The last three steps represent the environment. First, activities are filtered according to the activities interaction matrix; conflicted activities are removed and synergies are considered. At the second step, province and country level variables are modified according to the remaining activities and the activity effect matrix (which defines the effect of activities on variables). The final step applies the cross-impact matrix to update the variables.

3.5 C2 Approaches

C2 approaches for the current simulation model are described in Table 2. The continuity from one approach to the other is obvious and came naturally during the design. However, designing *Edge* proved to be a more difficult task than it seemed at first. Consequently, current Edge implementation is simply a low-latency version of Collaborative. A custom multi-agent system was created to implement the planning process. One or many agents use a utility function that calculates the expected gains of each combination of activities for determining the best activities to conduct. Agents in Coordinate interact together in order to evaluate the gain of joint activities for the provinces where they have units collocated. Collaborative and Edge improve this process by considering combinations of activities in any provinces.

Table 2: Planning approach and definition of the C2 approach space.

C2 Approach	Distribution of information among entities	Allocation of decision rights to the collective	Pattern of interaction among entities	Organization planning process
Conflicted	Between units of the same organization.	Each organization decides of its unit locations and activities.	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	Variables shared instantly between organizations having collocated units.	Each organization decides on its unit locations and non-conflicting activities.	With organizations having collocated units for preventing conflicting activities.	Like in *conflicted* but conflicting activities are not allowed.
Coordinated	Like in *de-conficted* + variables shared with 5 non-collocated units (delay: 5 iter).	Like in *de-conflicted* but interacting activities are considered first with collocated units.	With organizations having collocated units for considering interacting activities.	Like in *conflicted* but all possible interactions between activities with collocated units are considered.
Collaborative	Same as *coordinated* but with any number of units (delay 3 iterations).	All activities and unit locations are decided collectively.	With all organizations for deciding unit locations and activities.	All combinations of unit locations and activities are considered. Those with the higher impact are retained.
Edge	Organizations have an instant access to the ground truth.	Like in *collaborative*.	Like in *collaborative.*	Like in *collaborative*.

4 Results

Figure 3 shows the measures of success for the 270 combinations of changes in circumstances (54) and C2 approaches (5) corresponding to the more complex level. Changes in circumstances are represented on the horizontal axis for the self (missing organizations and information sharing delays) and on the vertical axis for the environment (enemy strength and crisis amplitude). For each C2 approach, the lower-left corner is the easiest change in circumstances while the upper-right corner is the most difficult one.

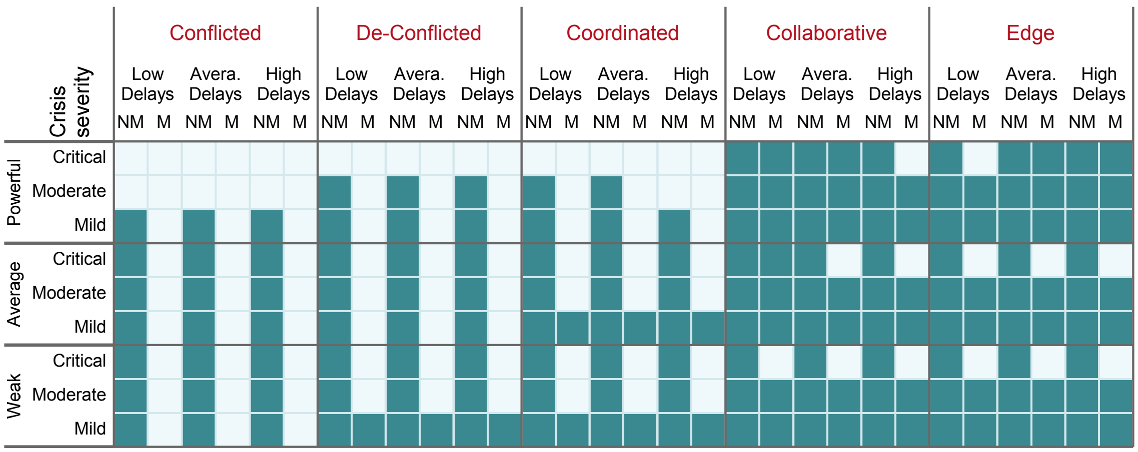
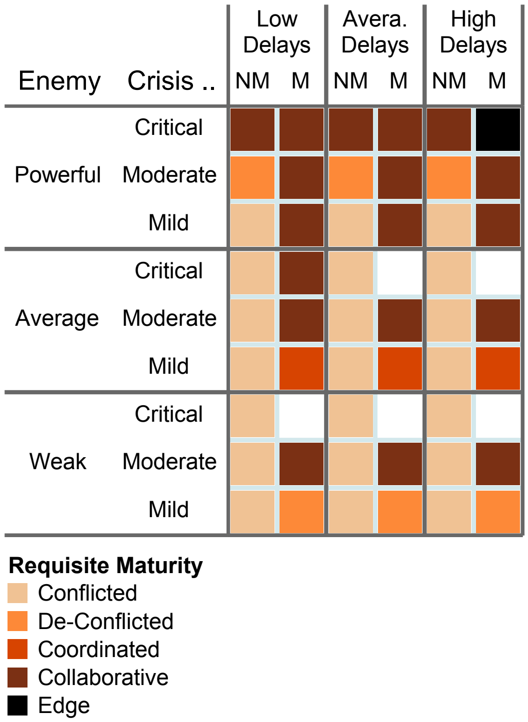


Figure 3: Measure of mission success (square in dark green means success) for the 270 conditions corresponding to the high level of complexity.

More capable C2 approaches successfully dealt with a wider range of changes in circumstances than less capable ones. However, some changes in circumstances were more favourable for less capable C2 approaches, like when no organizations were missing. Having organisations missing was the most difficult category of change in circumstances for all C2 approaches. Only Collaborative and Edge were able to cope almost entirely with it. All conditions succeeded in the case of the lowest level of complexity, hence the exclusion of this level of complexity for the remaining of this section.

Figure 4 shows the least capable C2 approach required for each change in circumstances (left) and as a percentage of changes in circumstances for each maturity level (right). The left-hand side shows that Edge offers little advantage over Collaborative, especially considering the additional resources (e.g. money) it could necessitate. Level 5 provides the higher level of agility with the ability to cope with 91% of all changes in circumstances. Right-hand side of Figure 4 provides a measure of requisite maturity. In the case of the level 4, which corresponds to Collaborative and below (excluding Conflicted), 33% of the changes of circumstances were coped successfully exclusively by Collaborative, the 50% remaining were coped successfully by De-Conflicted. The ability to switch from one approach to another could provide simpler and cheaper ways to conduct operation in 91% (49 out of 54) of the changes in circumstances. In summary, C2 agility can be a cost effective solution but does provide small increase in the ability to cope with changes in circumstances (agility) when comparing with adopting the most capable approach of a given level.



Level	Percentage of changes in circumstances
Level 5	91%
Level 4	89%
Level 3	56%
Level 2	50%
Level 1	39 %

Figure 4: Measure of requisite maturity: map of minimal C2 agility (left) and percentage of changes in circumstances with mission success (right).

According to Albert (2011), responsiveness, resiliency and flexibility are three enablers/components of agility (the three others proposed are versatility, innovativeness and adaptability). The second hypothesis of this experiment is that these enablers, plus situational awareness, are positively correlated with agility, i.e. with the ability to successfully cope with a large spectrum of changes in circumstances. The first enabler, responsiveness, represents the rapidity of coping with unexpected changes in circumstances. For the current simulation model, the recovery time corresponds to the number of iterations it takes for the variable *Government* to equal or exceed its initial value (0.3). A value of responsiveness of 1 corresponds to an immediate recovery time while a value of 1 corresponds to 31 iterations. The second enabler, resiliency, represents the ability of a self to repair, replace or reconstitute lost capability. In the context of the current simulation model, resiliency is the ability of not being too much impacted by a change in circumstances. Mathematically, resiliency is measured as the normalized value of how much the *Government* variable diverges from its initial value before recovering. The maximal value of resiliency (1) is achieved when the *Government* variable remains always over its initial value (0.3) and the minimal value (0) is obtained when the *Government* variable reaches 0 at any time during the simulation. Figure 5 illustrates an example of responsiveness and resiliency for one simulated condition. Finally, flexibility represents the possibility of the self to complete a task in different and more effective ways. For the current simulation model, the more flexible organizations are those who try to take into consideration other organizations' activities by choosing complementary activities, resulting in a larger variety of activities. Consequently, flexibility is calculated as the distinct count of the type of activities conducted by all organizations for a simulated condition. This number was normalized.

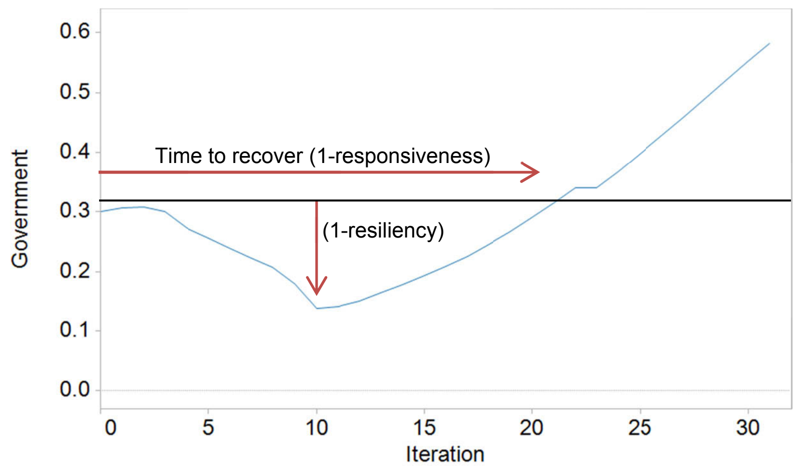


Figure 5: Illustration of responsiveness and resiliency for one condition (Collaborative, missing actors, moderate crisis severity, low comm. delays and powerful enemy).

Figure 6 shows a measure of the three enablers of agility for each C2 approach in relation with the measure of agility, i.e. the proportion of successfully coped change in circumstances. Hypothesis 2 is confirmed by the fact that responsiveness, $r(3)=0.996$, $p<0.01$, resiliency, $r(3) = 0.984$, $p < 0.01$, and flexibility, $r(3)=0.956$, $p<0.02$, are correlated with the measure of agility. Multivariate analysis of variance (MANOVA) revealed that the effects of C2 approaches on responsiveness [$F_{(4,112)} = 18.3$, $p< 0.001$], resilience [$F_{(4,112)} = 20.9$, $p< 0.001$] flexibility [$F_{(4,112)} = 24.2$, $p< 0.001$] are all statistically significant. It is not surprising that responsiveness and resiliency exhibit similar behavior since they derive from the same variable.

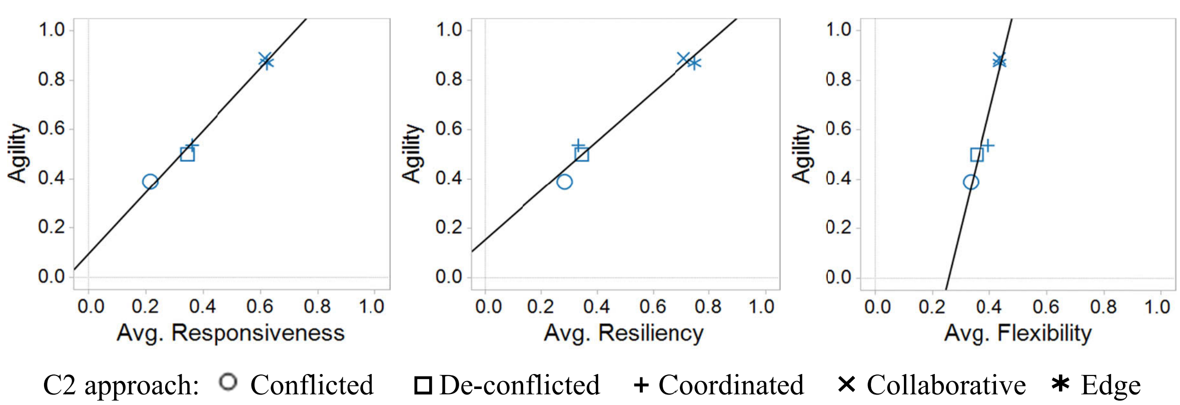
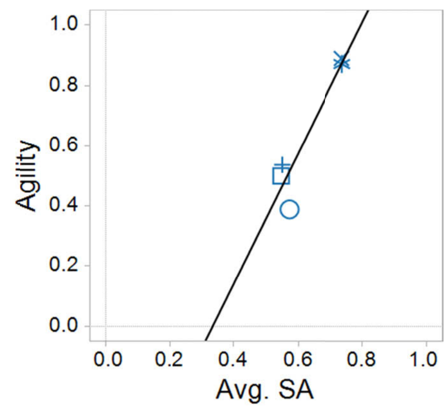


Figure 6: Relation between enablers of agility (responsiveness, resiliency and flexibility) and the number of mission success.

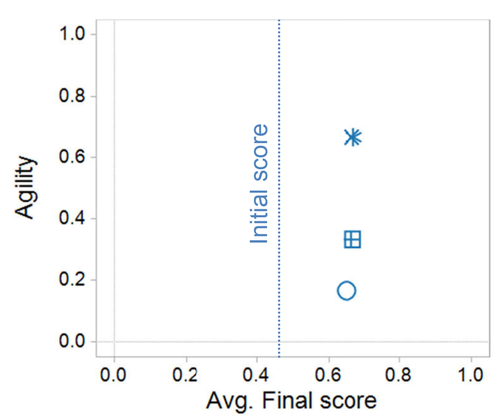
SA is another possible enabler of agility. As previously mentioned, this measure represents the gap between the current belief that organizations have of the variables and the ground truth. The SA measure presented here is renormalized between zero and one. Figure 7 shows that SA is clearly positively correlated with agility, $r(3) = 0.944$, $p < 0.05$. SA can explain the small performance improvement of Coordinated over De-Conflicted. In this case, non-optimal decisions were taken based on inaccurate (and then older) information. In this simulation model, SA is an enabler of agility because an organization operating in more capable C2 approaches, knowing what goes wrong, can tackle the problem faster, an observation supported by the higher level of responsiveness for more capable C2 approaches.



C2 approach: ○ Conflicted □ De-conflicted + Coordinated × Collaborative ∗ Edge

Figure 7: Situational awareness (SA) for each C2 maturity level compared to the total number of mission success.

One possible explanation for the greater level of agility of some C2 approaches would be their potential higher level of global performance, i.e. simply the fact that in some C2 approaches, organisations are more powerful because they globally create more synergies. For the given simulation model, global performance is measured from the average value of all variables. Figure 8 shows such measure in relation with agility. The initial "score", i.e. the average value of all variables when the simulation starts and displayed with a vertical dashed line, improves almost uniformly for all C2 approaches. The fact that the final score does not vary with the agility shows that agility and its enablers, including responsiveness, do not result from a better global performance but instead from the ability to tackle the problem more precisely and more quickly.



C2 approach: ○ Conflicted □ De-conflicted + Coordinated × Collaborative ∗ Edge

Figure 8: Initial score and average final scores for each C2 approach.

5 Conclusion

Simulating a comprehensive approach applied to a failing state proved to be an interesting method for studying agility. This context, for which success usually depends on effective interactions between organizations, is well suited to study C2 approaches. In addition, the results support the efficacy the comprehensive approach for solving crisis in failing states, hence the importance of better understanding it, including the agility aspect. The two hypotheses were validated but some nuances are worth mentioning. Moving from one C2 approach to the next more capable one had not systematically improved agility. Cases studies remain to be found to confirm this observation. Four enablers of agility, namely responsiveness, resiliency, flexibility, and SA, were found to be positively correlated with the measure of agility. Finally, the measure of agility is not dependent on the final score, suggesting that gaining in agility does not come from a higher level of performance but probably from the ability to solve the crisis in a timely manner. Additional investigations will be conducted to avoid the perfect score observed in the low complexity conditions while impacting the high level of complexity conditions.

This experiment did not evaluate the levels of C2 maturity explicitly, i.e. the ability of a higher level of maturity to change the C2 approach according the situation. Future work should consider testing the same simulation model but this time with the capacity of changing the C2 approaches during the mission. Still, it was possible to combine results of more than approach in order to get an approximation of C2 agility and the resulting requisite maturity map. In the current context, C2 agility can be a cost effective solution but does provide small increase in the ability to cope with changes in circumstances (agility).

The type of agility implemented in the simulation model was purely reactive. It would be interesting to repeat the same experiment with proactive organizations. In a proactive mode, organizations and systems could monitor their vulnerability to a broad range of (highly improbable) changes in circumstances and undertake pre-emptive and anticipatory measures like reorganizing some C2 resources for accelerating adaptation. The continuous self-assessment could be based on enablers of agility like responsiveness, information sharing and level of C2 maturity. These proactive measures would possibly be detrimental to the short-term performance of the system and require adaptation (Farrell & Connell, 2010), hence the need to dynamically find the appropriate trade-off between agility and other important aspects of the system.

In the current simulation model, Edge is implemented as a low-latency version of Collaborative. It was estimated that it would take about the same amount of resources to develop Edge as it took to develop the four other C2 approaches. The reason is that developing Edge cannot be based on small improvement over collaborative; it requires a disruptive approach. It would be worthwhile to test the same hypotheses with a version of Edge more in line with the concepts conveyed by its proponents (Alberts & Hays., 2003).

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