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Using a Functional Simulation of Crisis Management to Test the C2 Agility Model Parameters on Key Performance Variables

Topic 5 (Primary)
Experimentation, Metrics, and Analysis

Topic 6
Modelling and Simulation

Topic 2
Organizations and Approaches

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Increasingly, military and security organizations face the challenge to develop organizational structures and technologies that promote the agility required to deal with today’s complex operational environment. Organizational agility (or command and control (C2) agility) has been defined as transitioning from one governance and management (GM) approach (or C2 approach) to another as required by situation complexity (SAS-065, 2010; SAS-085, draft). This paper describes a study that aimed to test key concepts of the Organizational Agility model (Farrell, 2011; Farrell & Connell, 2010; Farrell, Jobidon, & Banbury, 2012). The study focused on two approaches – de-conflicted and collaborative – and tested the model’s parameters of resistance and size under varying levels of complexity. C^3Fire, a forest firefighting simulation, was used as task environment. It allowed varying contextual and organizational characteristics to create conditions where a transition can arise, and the emergent behaviours displayed by participants can be observed. Teams of four and six participants were trained in the two GM approaches and completed experimental scenarios including combinations of resistance and complexity. Several metrics were used to assess teams’ response, how they adjust their GM approach and how situational changes and approach transition impact team performance and teamwork. Initial findings are presented and discussed.

Introduction

The demands to support the cognitive aspects of decision making are growing rapidly, particularly in the context of high-reliability organizations that operate in dangerous or volatile dynamic environments and under severe constraints such as high risk, time pressure, complexity, and ambiguity (see Brehmer, 2007). Such dynamic and complex environments require a degree of command and control (C2). C2, particularly in a military context, can be defined as "the exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of a mission" (JP 1-02, 1994). Pigeau and McCann (2002, p. 56) define command as "the creative expression of human will necessary to accomplish the mission" and control as "those structures and processes devised by command to enable it and to manage risk". The principal functions of C2 mainly concern planning, directing, coordinating, and controlling the employment of available resources. Garstka and Alberts (2004) argue that the cognitive domain is paramount in C2, while the contributions of the physical and information domains are relevant to the extent that they enable operators to become aware of the situation, understand what is happening, make decisions, and take effective action. Executing C2 functions is cognitively demanding and engages a variety of cognitive resources or processes such as situation assessment, monitoring, recognition, problem solving, causal learning, search, planning, judgment, and choice (Gonzalez, Vanyukov, & Martin, 2005). The ability to coordinate these cognitive resources under time constraints is key to the successful exercise of C2. While C2 is predominantly associated with military operations, the same requirements are demanded in many other complex, dynamic, decision-making environments such as firefighting, air-traffic control, hospital emergency rooms, and incident command in crisis management.

C2 Agility Model

Agility can be conceptualized at a number of different levels; for instance at the team, organizational, or enterprise (group of organizations) level. Public safety and national defence organizations face the challenge to develop organizational structures and technologies that promote the agility required to deal with the complex demands of their endeavours. Private and public companies use Organizational Agility to set the conditions for effective and efficient services by improving and adopting situation-tailored C2 approaches (Farrell & Connell, 2010). Even though the entire C2 approach space contains an infinite number of approaches, NATO Research Task Group SAS-065 has identified five distinct C2 approaches, namely: conflicted, de-conflicted, coordinated, collaborative, and edge. In complex operations, a C2 approach is adopted by a group of organizations or entities, which together form a collective, in order to achieve the operational goals. Transitioning from one of these approaches to another—as required by the situation's complexity—has been defined as C2 Agility (Farrell & Connell, 2010; SAS-085). Because the most appropriate C2 approach may not have been selected at the onset of an endeavour, it is important that entities can transition from one C2 approach to another. The C2 approach space has three primary dimensions (SAS-065, 2010): Allocation of Decision Rights (ADR), Distribution of Information (DI), and Patterns of Interaction (PI). ADR is the formal and informal distribution of decision-making authorizations to the entities part of the collective, DI refers to the information sharing amongst the entities, and PI refers to the possible interaction configurations between members of the collective.

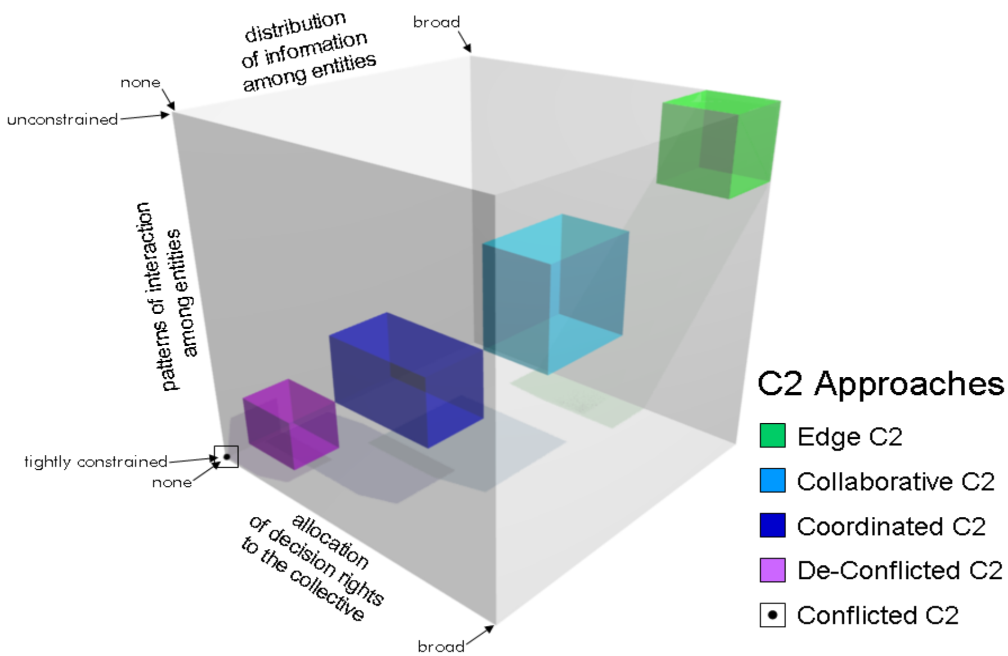

Figure 1. Command and Control Approach Space that show five distinct C2 Approaches (SAS-065, 2010)

Transitioning between C2 approaches takes time (Farrell, 2011; Farrell et al., 2012). There can be enablers and inhibitors to this change, which will speed up or slow down the "organizational momentum" as the collective moves within the C2 approach space. Transitioning from de-conflicted C2 to coordinated C2 should theoretically be shorter than going from de-conflicted C2 to edge C2 for a given set of enablers and inhibitors. For example, a collective of organizations can adopt a de-conflicted approach while the situation is stable and each entity can work effectively within its designated area of responsibility. However, an unanticipated catastrophic event or a significant disturbance can increase the overall complexity of the situation and the de-conflicted approach may no longer work. The collective will have to dynamically re-assess the C2 structures and transition to a more collaborative approach where ADR and DI are broad and PI is unconstrained in order to address the complexities of the event.

Primitives

The following primitives of the collective govern the transition dynamics (time it takes to transition and the amplitude of the transition) between different C2 approaches (Farrell & Connell, 2010; Farrell, 2011):

1) Collective *size* (e.g., people, budget, infrastructure, equipment, resources);

2) Collective *resistance* (e.g., system attributes that restrain the collective from changing C2 approaches such as lack of trust or malfunctioning technology);

3) Collective *stiffness* (e.g., an entity characteristic related to the increase in degree of discomfort as the entity moves farther away from its most comfortable C2 approach).

Together, collective size, resistance and stiffness determine the robustness (stability) and responsiveness (time profile) as the collective transitions from one approach to another.

Assumptions

The C2 Agility model includes certain assumptions relating to the *primitives*. For example, an organization's size affects a number of attributes, particularly responsiveness. According to the model (Farrell, Jobidon, & Banbury, 2012), as the collective's size gets smaller, it would respond faster with smaller overshoot and it would be able to keep up with quick changes. Conversely, as the collective's size gets larger, the system is slower to respond. Therefore, a small organization is more responsive than a larger one. The collective size is useful when comparing agility across different collectives or the same collective in different situations.

Resistance is only apparent when moving through the C2 approach space. It is similar to the resistance a plane feels when moving through the air or a submarine moving through water. Although the plane may experience less resistance, it may also overshoot the intended position. On the other hand, the submarine may be very slow to reach the intended position due to the large resistance of the water. In the same manner, an enabling entity within the collective might facilitate moving from one C2 approach to another by promoting the appropriate levels of ADR, PI, and DI while an antagonistic entity may inhibit any movement towards another C2 approach[1].

Stiffness refers to the extent to which the collective is comfortable with a certain C2 approach. If the collective finds itself in the region of the C2 approach space with which it is comfortable, there is no tendency to move from this position. If the collective adopts an approach with which it is unfamiliar, then there will be a tendency to move back towards where it is more comfortable. This causes tension within the organization and may affect the responsiveness of the transition.

Another assumption of the model is that the collective will be most efficient and effective when the C2 approach matches the level of complexity. That is, the model posits that while there is a cost for moving to one approach to another, a cost also comes with the

[1] One must keep in mind that resistance goes both ways. That is, an antagonist entity within the collective could be one who promotes collaboration when in fact the situation complexity is low and requires de-conflicted.

collective operating at a level that is higher than required. For example, a collective, operating at a collaborative level when only de-conflicted is required, will be effective (accomplish objectives) but not as efficient (additional costs for broad DI and unconstrained PI). Therefore, the C2 approach adopted should match the required approach to maximize goal achievement and minimize costs.

Purpose of the Study

In this paper, we describe a study that aims to test and evaluate key concepts of the C2 Agility model (Farrell, 2011; Farrell & Connell, 2010; Farrell, Jobidon, & Banbury, 2012). In particular, the study focuses on testing empirically the impact of two parameters, size and resistance, on transition time. Several metrics are used to assess teams' response, how they adjust their C2 approach and how situational changes and approach transition impact team performance and teamwork. The study is focused on two approaches – de-conflicted and collaborative.

The following hypotheses are derived from the C2 Agility model (Farrell, 2011; see Table 1):

1. Low size and low resistance would allow making the transitions in time, t_1 (critically-damped).
2. Low size and high resistance would yield $t_2 > t_1$ (over-damped response).
3. High size and low resistance would yield $t_3 > t_1$ (under-damped response).
4. High size and high resistance yield $t_4 = t_1$ (equally scaled from low size and low resistance).

Table 1. Hypotheses summary.

	Low resistance	High resistance
Low size	t_1	$t_2 > t_1$ over-damped
High size	$t_3 \approx t_2 > t_1$ under-damped	$t_4 = t_1$

Figure 2 shows critically-damped, under-damped and over-damped responses along with their corresponding settling times. The settling time corresponds to the time from t = 0 to the point in time where the response is always within 3% or 4% of the steady state value. A critically-damped response has one small overshoot and then settles into a steady state response. An under-damped response has several oscillations before settling down. An over damped-response has no overshoot and takes some time to reach the steady state response. It will be difficult to observe whether there is overshoot or undershoot because this would require a high sampling rate of the actual C2 Approach. However, it is possible to at least measure the settling times (t_1, t_2, t_3, and t_4) and determine whether they match the relative values in Table 1.

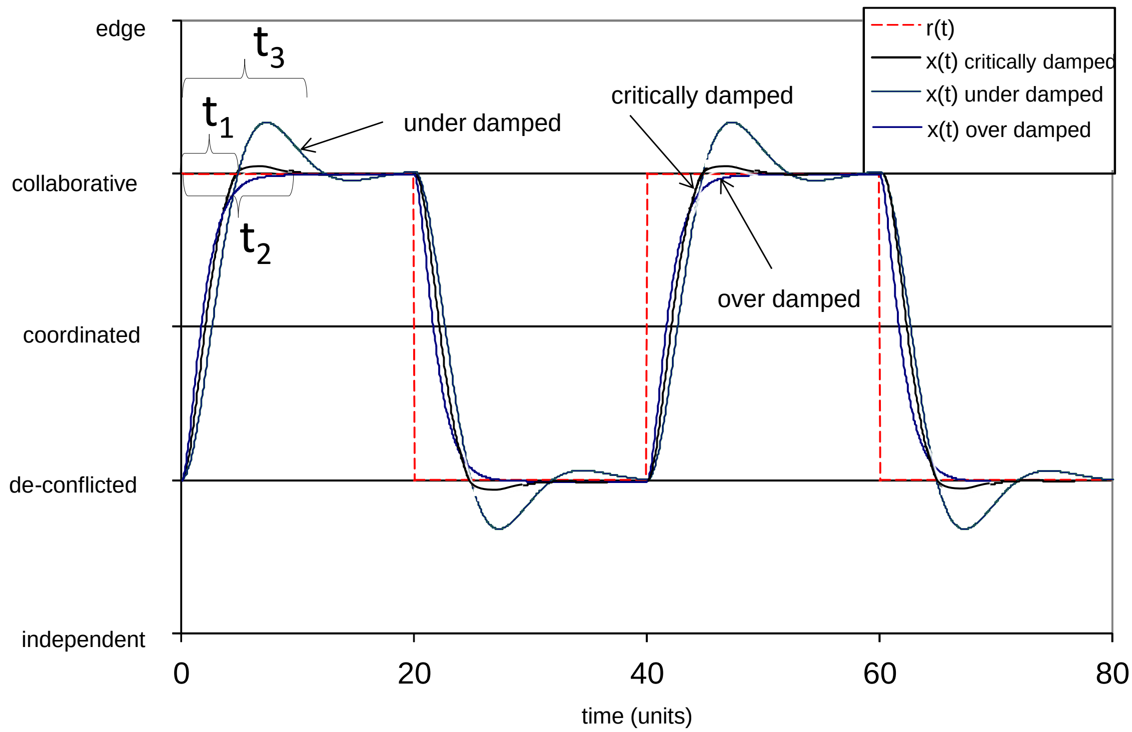

Figure 2. Critically-damped, under-damped, and over-damped responses.

Although transition time is the key dependent variable for hypothesis testing, it is not reported on in this paper but will be the topic of subsequent papers. A key objective of this initial study is to validate a method and design tailored to address the main assumption of the C2 Agility Model. Thus, a secondary purpose of this study is to examine the impact of team size and resistance on key performance variables. This paper presents initial findings on the overall performance, the coordination effectiveness, the level of goal commitment, and the subjective experience of participants. These variables also allow for the evaluation of the validity of the study's design and the experimental conditions. The preliminary analysis completed to date focuses on these key performance variables.

Microworld Simulation

In order to test the transitioning from one approach to another - as required by the situation's complexity - a microworld simulation with the capability to develop team-based crisis management scenarios and support teamwork will be used. The microworld simulation offers a good compromise between ecological and internal validity by creating controlled experiments in realistic simulations of crisis management rather than relying on field studies. Microworlds offer the great advantages of experimental manipulation and control, without stripping away the complexity and the dynamic nature of the task.

They retain the basic or essential real world characteristics while leaving out other aspects deemed unnecessary for the purposes at hand. Therefore, process and performance measures are captured in a real-time experimental situation involving different types of intra-organizational interactions. The 'Cognitive Network Tracing' (Banbury & Howes, 2001) approach allows researchers to assess the teamwork processes employed by teams as they are trying to achieve goals within the simulation. The Cognitive Network Tracing can be used to provide a fine-grained indication of the processes and communications between team members. The recent work of Cooke and Gorman (2009) proposed an interactionist approach to the assessment of team performance that capitalizes on variability in cognition and behaviour distributed across time, people, and the environment. This approach involves the deliberate propagation of scenario events, or 'seeds', in the collaborative simulation environment and the subsequent observation of their trajectory throughout the team. Clearly, the information seeds must be both critical enough to demand action by team members, and salient enough for the experimenter to observe their subsequent effect on team members' behaviour. The simulation environment used as experimental platform for this study is C^3Fire (Granlund, 2003), a forest firefighting simulation used to reproduce a complex and dynamic C2 situation.

Method

Participants

The experimental protocol calls for ninety participants. They will be recruited[2] from the Université Laval campus in Québec City, Canada, and assigned to four- or six-person teams. Participants have the option to enroll in the experiment alone or to enroll as a team (of two or four participants). The experimenters keep track of the extent to which team members know one another since previous personal knowledge of team members can affect some team-related metrics. Unaccompanied participants are matched with other participants by the experimenter. Each team size includes two confederates, so that four-person teams include two participants and two confederates, and six-person teams comprise four participants and two confederates. These confederates are an integral part of the team, but their actions are scripted in order to manipulate the level of resistance (see Design). Participants receive an honorarium in exchange for their participation. With ninety participants, 15 four-person teams and 15 six-person teams can be created. Seven four-person teams and seven six-person teams have already completed the experiment, for a total of 42 participants.

Material

C^3Fire is used as the microworld task environment for the study (Granlund, 1998; Granlund & Granlund, 2011). C^3Fire is a command, control and communications (C^3) simulation environment for teamwork using forest firefighting mission scenarios. The

[2] It is expected that all experimental runs will be completed by September, 2013.

goal of each mission is to extinguish as much of the fire as possible while saving houses and inhabitants of neighborhoods spread on the map (see Figure 3). The fire model in the simulation is based upon actual research on forest fires and the C^3 context is based on case studies of emergency coordination centers (Brehmer, 2004). The scenarios are easily modifiable and C^3Fire is appropriate for a functional simulation of crisis management since it involves time pressure, uncertainty, and teamwork: three key considerations for crisis management teams. Like real-life crisis management situations, the simulated task requires dynamic team decision making and involves regulating a dynamic system in which: (i) a series of activities are required to reach and maintain the overall goal, (ii) activities depend on the outcome of previous activities, (iii) task parameters are continuously varying in response to changes, and (iv) tasks are accomplished in real time.

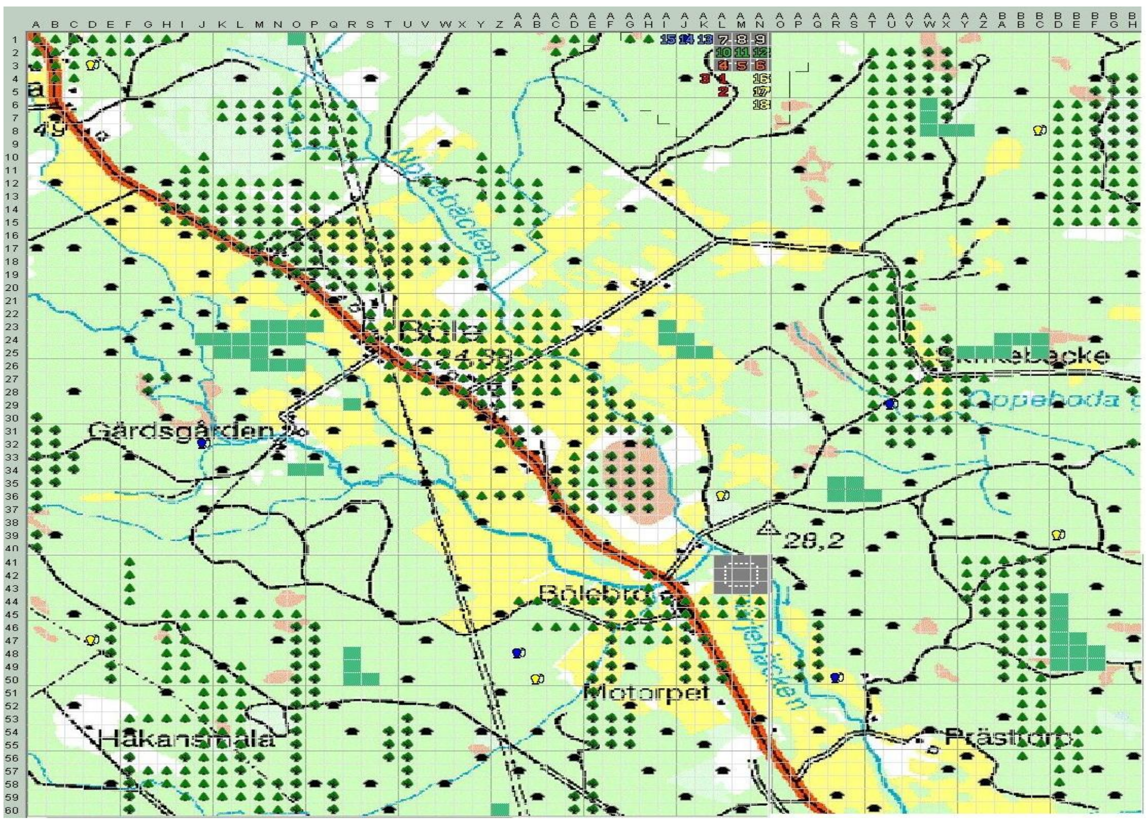

Figure 3. An image of the C^3Fire map used in this study.

The C^3Fire interface consists of a geospatial map, displayed on a 60 × 60 cell grid built up by a set of four interacting simulation layers: fire, geographical objects, weather, and intervention unit. The *fire layer* defines five different states for each cell of the map, represented by a colour code: on fire (red), extinguished (brown), burned-out (black), firebreak (grey) or clear (no color). Starting positions of the fires are previously defined in a configuration file. Participants only have a restricted vision of the fire, which means that it only becomes visible if a unit discovers it by moving close by. The burning of an intact cell can only occur if an adjacent cell is already on fire. If a cell is not extinguished within a certain time interval after ignition, it turns black and is considered burned out. A firebreak can only be built on an intact cell. A new fire cannot be ignited on a cell that has been extinguished, burned out or is protected by a firebreak. The *geographical objects layer* corresponds to the different types of physical entities displayed on the map (plain, pine, birch, swamps, water tanks, fuel tanks, transit point or house). A cell can contain any one of these objects but only one at a given location. The content of a cell directly influences its ignition time. However, swamps, transit point, water tanks, and fuel tanks cannot ignite.

The *weather layer* determines the strength and direction of the wind. The stronger the wind, the faster the fire spreads to neighboring cells in the same direction as the wind blows. Changes in wind strength and direction are also scripted in the configuration file. Finally, the *unit layer* refers to the intervention units (i.e., the resources) that the participants control. There are six types of units in C^3Fire: firefighters (FF), fire breakers (FB), water tankers (WT), fuel tankers (FT), search units (S), and rescue units (R), each represented by a numbered icon colour-coded by type of unit. Each type of unit has a specific role: FF extinguish fires by moving to a burning cell; FB create firebreaks to control the spread of fire; FT and WT supply fuel and water, respectively, to the other units; S explore the map in order to find new fires and survivors; and R collect the survivors, and bring them to a safe transit point. In order to move a unit, participants must click on it and drag it to the desired destination cell. The FF, FB, WT, and R have a limited fuel reservoir, which is refilled by moving a FT to an adjacent cell. Similarly, the FF also have a limited water reservoir that needs to be refilled by moving a WT to an adjacent cell. WT and FT have limited tanks and have to be refilled by moving respectively to water tanks and fuel tanks distributed on the map.

Each C^3Fire experimental scenario completed by teams is recorded with the use of the Morae software (TechSmith, Okemos, MI). Therefore, every event that happens in the microworld (e.g., keystrokes) is recorded and continuous screen capture is available to the experimenters. Team members are able to communicate with each other via headsets and all communications are recorded using the Teamspeak freeware (TeamSpeak Systems, Krün, Germany).

Design

This study is based on a 2 × 2 × 2 mixed design with team size (four or six) as a between-subject factor, and resistance (low or high) and situation complexity (low or high) as within-subject factors.

For this study, teams of four and six participants are compared. All teams receive training for the de-conflicted as well as the collaborative C2 approaches, before completing two experimental scenarios. Therefore, the collective's size is manipulated while the stiffness parameter remains constant as all teams, after training, are 'comfortable' with both the de-conflicted and the collaborative C2 approaches.

Two levels of resistance, low and high, are compared. The resistance parameter is manipulated by adding two confederate players per team. The confederates act as participants and they fully participate in the experiment exactly like the others. However, their actions and behaviours are scripted. One confederate plays an enabling role by acting as a 'good' team player (low resistance) while the other confederate plays an antagonistic role by acting as a 'bad' team player (high resistance). The confederates scripts' were developed from questionnaires on three constructs that have been shown relevant in the field of crisis management teams (group potency, goal commitment, and trust; see, e.g., Blais & Thompson, 2009; Guzzo, Yost, Campbell, & Shea, 1993; Klein, Wesson, Hollenbeck, Wright, & DeShon, 2001), as well as from a model of team sensemaking that identifies enabling and inhibiting behaviours (Powers, Stech, & Burns, 2010).

The level of resistance is varied between scenarios. That is, in one of the two experimental scenarios the enabling confederate plays his/her role while the antagonistic confederate takes a step back and acts as a normal participant (but still play the game to avoid raising suspicion). The situation is reversed in the other experimental scenario, with the confederate acting antagonistically as per his/her role while the enabling confederate acts as a normal participant (but again still plays the game to avoid suspicion from the other participants). The order of these two experimental scenarios (enabling and antagonistic confederate active) is counterbalanced.

The complexity of the situation (low or high) is also manipulated in order to create significant disturbances that put pressure on teams to transition from one approach to another within scenarios. The experimenter, hidden from participants in the monitoring room, has control over parameters affecting situation complexity. Both experimental scenarios begin at a baseline level and participants remain at this level of complexity for two to three minutes before any critical events or changes occur and the complexity rises to a higher level. Changes in complexity must be immediate and punctual events to facilitate the monitoring of teams' response to these changes. Each experimental scenario contains two cycles of low and high complexity. Figure 4 depicts an example of the evolution of situation complexity throughout a scenario.

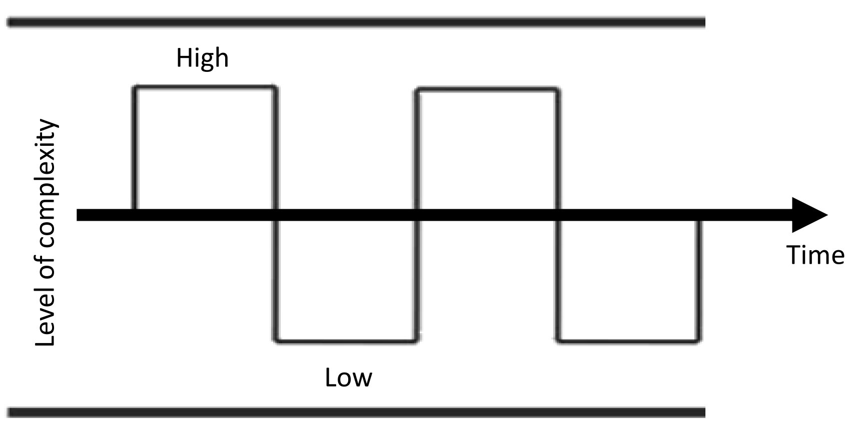

Figure 4. Two-cycle square wave representing the variation in the level of complexity over time throughout the experimental scenarios.

High complexity situations are created through two means. First, the appearance of new fires combined with changes in wind strength and direction at predetermined times cause the fire to spread more quickly. Second, the experimenter controls a sabotage unit that is sent to disable some of the participants' units. This sabotage unit is invisible to the participants. Once a unit is sabotaged, it becomes paralyzed and it cannot move anymore. Therefore, participants are forced to use only the remaining units and they are placed in a high complexity situation by having fewer resources available to achieve their mission.

Low complexity situations are created through the resolution of the high-complexity situations described above. That is, to drop the level of complexity brought on by the increased spread of fire and the decrease in firefighting resources from sabotaged units, aircrafts filled with water circle around the fire and drop water to help participants extinguishing the fire (nine cells at a time). These aircrafts are controlled by the experimenter and they are invisible to the participants. However, participants receive a message via their viewer panel telling them that help has been deployed to assist them with the fire.

Procedure

The experiment is run in a single 3 to 3.5-hour session that includes a training phase and an experimental phase. For the first part of the session, participants complete two training phases to familiarize themselves with the de-conflicted and the collaborative approaches, respectively. After a 5-minute pause, participants are presented with a short tutorial reminding them of the two approaches (de-conflicted and collaborative) and the goals of their mission. They are instructed to use either approach, depending on what they deem appropriate for the situation. Then, all teams perform two 40-minute experimental scenarios, each followed by a series of questionnaires. Therefore, the session unfolds as follows:

General tutorial → Familiarization → Collaborative tutorial → Collaborative training → De-conflicted tutorial → De-conflicted training → 5 min pause →Tutorial → Scenario 1 → Questionnaires 1 → Scenario 2 → Questionnaires 2 → Debriefing → Post-debriefing questionnaire.

Training Collaborative and De-Conflicted Approaches

Participants receive a tutorial specific to each C2 approach. One tutorial teaches them how to play C^3Fire using the collaborative approach while the other teaches them how to play using the de-conflicted approach. The order of these two training sessions is counterbalanced. While training for the collaborative approach, the participants are not attributed any specific functions or units a priori. Therefore, the tutorial encourages players to collaborate and to redistribute and reallocate units amongst themselves in order to accomplish the task efficiently (see Figure 5).

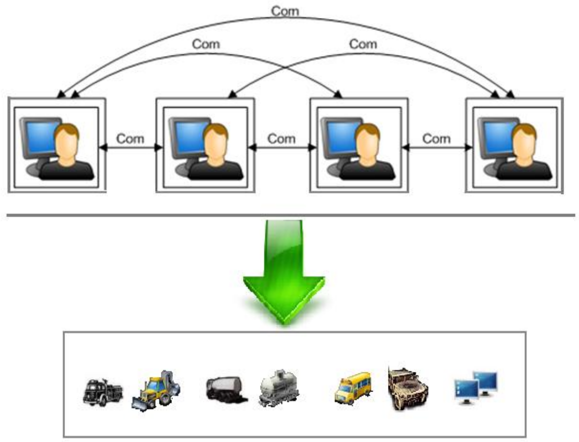

Figure 5. Allocation of resources for the collaborative approach in C^3*Fire.*

For the de-conflicted approach, participants have pre-allocated roles and are highly interdependent in accomplishing the task. As team size (four or six people) is an independent variable, the total number of units available to the participants (18 units) is kept constant during the training sessions. Each team member is assigned a specific role depending on the team size (See Figure 6).

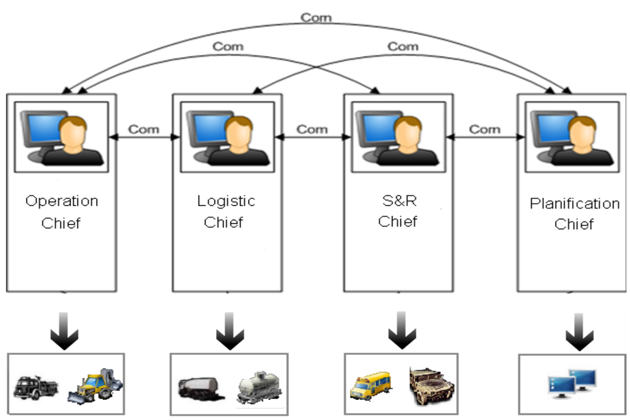

Figure 6. Allocation of resources for the de-conflicted approach in C^3*Fire.*

Metrics

A set of cognitive and teamwork metrics was developed to assess how teams respond to changes in resistance and situation complexity and how they adjust their C2 approach, as well as the impact on team performance and teamwork.

Metrics are related to the C2 approach space three primary dimensions (SAS-065, 2010): Allocation of Decision Rights (ADR), Distribution of Information (DI), and Patterns of Interaction (PI). The analysis of communication and Social Network Analysis (SNA) provide both visual and quantitative representations of the relationships between team members, and tracks the evolution of the team's structure over the course of a scenario. SNA will be used as an indicator of the level of ADR, PI, and DI, and help in determining the C2 approach used at a given time. ADR will be mapped to the social network metric called 'sociometric status' that measures 'how busy' a node (i.e., a team member) is relative to the overall number of nodes in the network. PI will be mapped to the social network metric 'centrality' that measures the distribution of information (or power) within the team. Finally, DI will be mapped to the social network metric 'density' that refers to the degree of connectedness of a network; that is, it shows if a network is dense in connections or scarce (Benta, 2005).

As the aim of this paper is to present initial findings and to evaluate the validity of the study's design, the following section describes some metrics that were used for the preliminary analyses, but it does not constitute an exhaustive list of all the metrics that will be analyzed in this study.

Settling Time

To assess transitions from one C2 approach to another, we will analyze measures such as the time teams take to adapt their C2 structure to changes in situation complexity, and more particularly the settling time. As mentioned previously, the settling time corresponds to the time from t = 0 to the point in time where the response is always within 3% or 4% of the steady state value.

Performance

Performance was measured through firefighting efficiency. In the C^3Fire scenarios, one of the teams' main tasks was to extinguish the fire in order to achieve their objectives. A team that can extinguish fire at a greater pace will generally be able to control the threat to civilians, houses, and forest better. The number of extinguished cells was used as a firefighting efficiency index, which was calculated as follows:

$$\frac{Total\ number\ of\ cells\ extinguished}{Duration\ of\ the\ period}$$

Coordination

Coordination effectiveness was evaluated based on the time each unit spent without resources (i.e., water or fuel). This is a measure of the effectiveness of resource-oriented coordination. This type of coordination refers to processes that serve primarily to manage dependencies between activities or resource dependencies (Crowston, 1997). It provides an excellent indicator of the efficiency in performing the water and fuel refill process, which requires coordination between the various units. Coordination effectiveness was calculated as follows:

$$\frac{Total\ time\ without\ resources\ for\ all\ units}{Duration\ of\ the\ period}$$

A score of 0 represents optimal coordination effectiveness, as a unit would never have an empty water or fuel tank during the scenario.

Goal commitment

This questionnaire measures the degree of team investment in achieving their goals (Aubé & Rousseau, 2005; Klein, Wesson, Hollenbeck, Wright & DeShon, 2001). Participants have to rate seven items linked to a five-point scale ranging from *not true at all (1)* to *totally true (5).* For example, one item aimed to measure perceptions of goal difficulty ("It is hard to take this goal seriously"). A higher score on the scale means that team members are committed to the goals and determine to achieve them (Weldon & Weingart, 1993). Studies show that team goals are directly related to team performance (for a review see Rousseau, Aubé, & Savoie, 2006).

Post-debriefing questionnaire

The post-debriefing questionnaire assessed participants' awareness of the experimental conditions, particularly the levels of situation complexity and the presence of confederates. Participants had to rate on a five-point Likert scale ranging from *strongly disagree* (1) to *strongly agree* (5) whether they perceived that their workload was at times high and at times low during the scenarios and whether they realized that there were confederates on their team.

Results

For preliminary analyses, we selected the most relevant metrics in order to validate the experimental conditions created from the 2 × 2 × 2 mixed design with team size (four or six) as a between-subject factor, and resistance (low or high) and situation complexity (low or high) as within-subject factors. It should be noted that for the purpose of this paper, situation complexity was assessed via a post-debriefing questionnaire. All other metrics encompassed the whole scenario.

Settling Time

The analysis of the settling time is underway but has not been completed. These results will be reported in follow-on publications.

Performance

Figure 7 shows mean number of cells extinguished as a function of the team size and the resistance factor. A repeated-measures analysis of variance (ANOVA) revealed that the number of extinguished cells does not vary between four-person teams and six-person teams, $F < 1$, $p = .570$. Similarly, the level of resistance did not have a significant impact on performance, $F(1, 12) = 2.131$, $p = .170$, and neither did the size by resistance interaction, $F < 1$, $p = .880$. As a way to ensure that both scenarios had an equal level of difficulty, a repeated-measures ANOVA was also calculated with the scenarios as a within-subject factor. Results showed no significant difference in performance across the two scenarios, $F(1, 13) = 1.307$, $p = .274$.

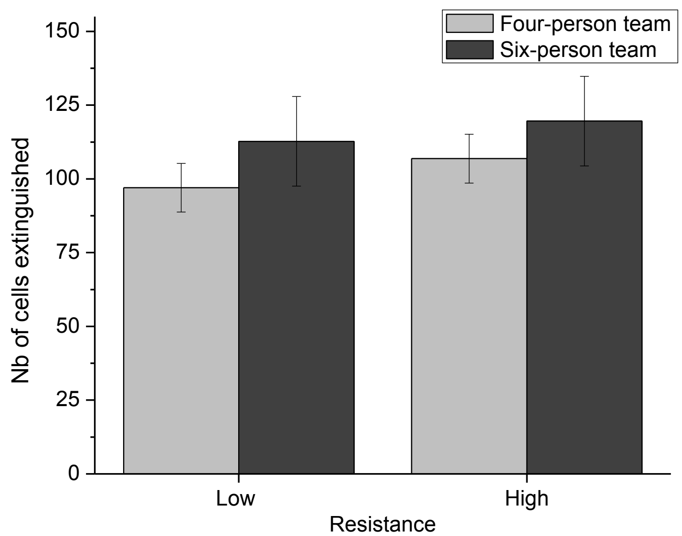

Figure 7. Mean number of cells extinguished as a function of team size and resistance. Error bars represent standard errors.

Coordination

A repeated-measures ANOVA showed that coordination did not significantly differ between the two team sizes, $F < 1$, $p = .391$, levels of resistance, $F < 1$, $p = .722$, or size by resistance interaction, $F(1, 12) = 1.191$, $p = .296$ (see Figure 7). Again, to ensure that both scenarios were equivalent, a repeated-measures ANOVA was calculated with the scenarios as a within-subject factor. Results showed that coordination did not significantly differ across the two scenarios, $F(1,13) = 3.168$, $p = .098$).

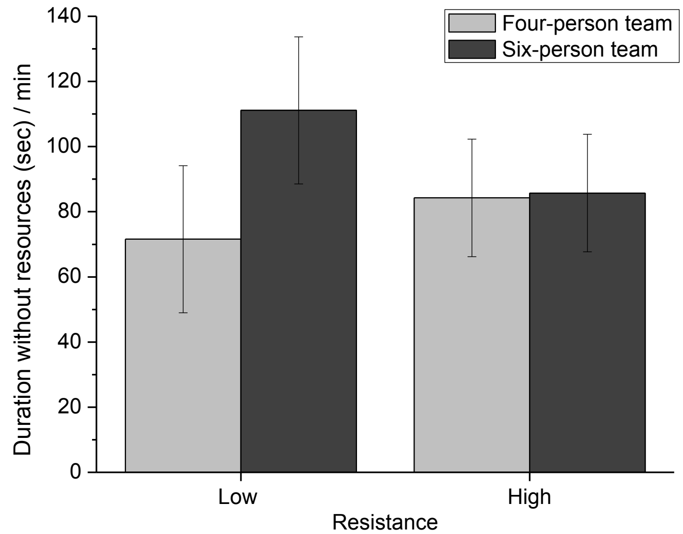

Figure 8. Mean coordination effectiveness as a function of team size and resistance. Error bars represent standard errors.

Goal Commitment

Figure 9 shows the mean goal commitment score as a function of team size and resistance. A repeated-measures ANOVA revealed that goal commitment was not affected significantly by team size, resistance, or the interaction between these two factors, $F < 1$, $p = .560$; $F(1, 12) = 3.058$, $p = .106$; and $F < 1$, $p = .343$, respectively. In order to investigate whether the mean goal commitment score varied across scenarios, a repeated-measures ANOVA was conducted with scenario as a within-subject variable. Results showed that the level of goal commitment was similar across the two scenarios, $p > .05$.

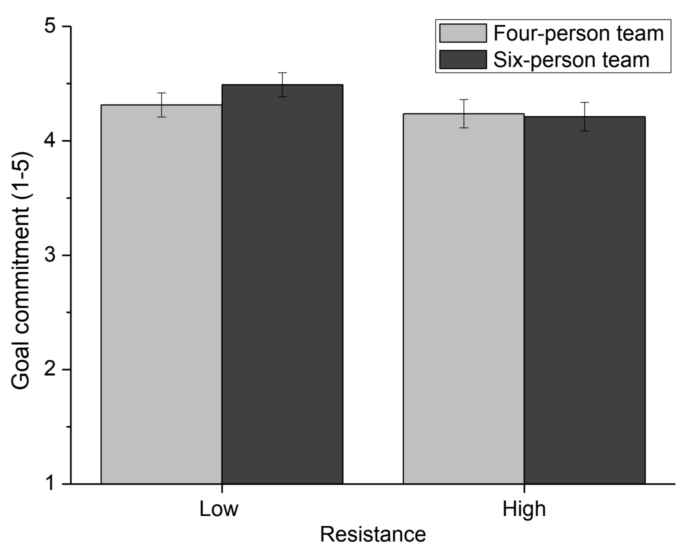

Figure 9. Mean goal commitment score as a function of team size and resistance. Error bars represent standard errors.

Post-debriefing Questionnaire

Participants had to rate on a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5) whether they perceived that: ‘At certain points during the scenarios, the workload was high’ and ‘At certain points during the scenarios the workload was low’. Out of the 42 participants, 62 % responded ‘strongly agree’ or ‘somewhat agree’ that the workload was at times high and at times low. Participants also had to rate the following statement: ‘During the experiment, I realized that there were confederates on my team’. Ninety-five percent of the participants answered either ‘I strongly disagree’, ‘I somewhat disagree or ‘I neither agree nor disagree’ to this question. These results suggest that participants perceived that the level of complexity varied throughout scenarios and that a vast majority of them were not aware of the presence of confederates on their team.

Discussion

In the context of C^3Fire, the overall team performance can be assessed by the number of extinguished cells by firefighters, while the overall team coordination is based on the time each unit spends without resources to function. The findings suggest that team size may not affect overall team performance or overall coordination effectiveness. However, a lot of variability was observed between teams in performance and coordination. A posssible explanation for some of that variability is that during the scenarios, team members are free to adopt the structure, role and resources allocation that they think best suit them and/or the situation. Giving participants this kind of flexibility allows for a greater potential of variability. This is consistent with previous assumptions that when role and resources allocation is vague, team members take advantage of their flexibility and different teams behave differently during the completion of their tasks (e.g., Alberts & Hayes, 2003; Cooney, 2004).

While not statistically different, coordination effectiveness appeared to be better amongst four-person teams than six-person teams in the lower resistance condition. According to the C2 Agility model (Farrell et al., 2012), a smaller team size would respond faster with smaller overshoot and it would be able to keep up with quick changes. Conversely, as the team size gets larger, the system would be slower to respond. Our preliminary findings could suggest that the C2 Agility model assumptions may not be confirmed regarding the overall performance but that the smaller team size may be able to better coordinate and manage resources dependencies, and be able to keep up with quick changes during the scenario. It is important to keep in mind that the preliminary results presented here are based on the overall 40 minutes scenarios without consideration for the varying level of situation complexity. Future analyses of performance and coordination, in which phases of high and low complexity within scenarios are taken into account, might yield some differences across team sizes.

Somewhat surprisingly, at this point the resistance parameter does not appear to have an impact on overall performance or coordination. It is possible that the use of confederates in order to manipulate resistance during experimental scenarios is not sufficient to observe sigificant changes in team effectiveness. However, with six-person teams there seems to be a trend towards better coordination under a high level of resistance compared to low resistance. In other words, when the confederate plays an antagonistic role by acting as a 'bad' team player and is not encouraging the redistribution of roles or tasks, the six-person teams seem to achieve better coordination than when the confederate enables reorganization. It could be that for six-person teams, not having a team member encouraging reorganization allows team members to work more effectively within their designated roles and tasks. If these results were confirmed with a full sample and more in-depth analyses, it would be in line with some previous findings showing that explicit role allocation allows team members to develop knowledge of their own and others' roles, which provides mutual expectations that allow teams to coordinate and make predictions about the behaviour and needs of their teammates (e.g., Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995). Upcoming analyses focused on time periods and transitions between C2 approaches should shed more light on the effect of high or low resistance on teams' structure and effectiveness.

These initials analyses also revealed that the level of difficulty of the two C^3Fire experimental scenarios appears equivalent with regards to teams' performance and coordination. The use of two different scenarios was necessary in order to manipulate resistance with help of the two confederates (each one being active during only one of the two scenarios). These results suggest that the overall level of difficulty is comparable across the two scenarios.

Preliminary results indicate that goal commitment is similar across team size and level of resistance. Importantly, participants reported high levels of goal commitment for every experimental scenario. These findings indicate that participants were highly engaged in the tasks and motivated to accomplish their goals. The C^3Fire microworld platform presents realistic simulations of crisis management that are stimulating for the participants, justifying its use in the present study.

Results from the post-debriefing questionnaire revealed that the manipulation of situation complexity was fully reflected in the scenarios as almost two thirds of participants indicated that they perceived their workload to be at times low and at times high. This suggests that our manipulation of situation complexity was valid and effective. The confederates were also good at portraying participants as 95% of the participants did not realize that there were confederates on their team.

Conclusion

This study aims to validate a subset of the concepts hypothesized in the C2 Agility model (Farrell, 2011; Farrell & Connell, 2010; Farrell et al., 2012). The C2 Agility model postulates that during an operation, the C2 approach required to optimally deal with a given situation varies as a function of the complexity of the situation.

Preliminary findings did not reveal significant difference across team size and levels of resistance in terms of performance and coordination. A visual examination of the data suggests that coordination might be better in smaller teams compared to larger teams, especially under conditions of low resistance. However, a bigger sample size and further analyses are needed to determine whether this trend is significant. Variability in coordination seems to be high, which could come from the ambiguity associated with the lack of explicit role or task allocation to each team member (e.g., Alberts & Hayes, 2003; Cooney, 2004). Low resistance appears to influence coordination effectiveness negatively amongst six-person teams. It is important to remember that these initial findings are based on the overall 40-minute scenarios, without consideration for the variations in situation complexity. More teams and further analyses are needed to assess the impact of the complexity parameter by analyzing separately the different periods of high and low complexity in the scenarios. In addition, examining the content of communications and other teamwork indicators (e.g., cluster analysis; see Duncan & Jobidon, 2008) is critical in order to determine whether teams transition from one C2 approach to another depending on situation complexity. The impact of size and resistance on transition time will also be assessed. Several other metrics will be used to assess teams' response, how they adjust their C2 approach and how situational changes and approach transition impact team performance and teamwork.

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