13th ICCRTS
"C2 for Complex Endeavors"

Spontaneous Role Adoption and Self-synchronization in Edge Organizations Using the ELICIT Platform

Topics 5, 4, 6

Matthew Duncan

And

Marie-Eve Jobidon

Defence Research and Development Canada Toronto

Point of Contact: Matthew Duncan

Defence Research and Development Canada Toronto

1133 Sheppard Ave West

Toronto, Ontario M3M 3B9 Canada

416-635-2000-3211

Matthew.Duncan@drdc-rddc.gc.ca

Spontaneous Role Adoption and Self-synchronization in Edge Organizations Using the ELICIT Platform

Abstract

This research used the ELICIT platform (Parity, 2006a) to investigate spontaneous role adoption and self-synchronization in Edge organizations. Behavioural indicators associated with explicit roles in a Hierarchical organization (e.g., Team Leader, Team Member, etc) were compared with the same indicators derived from members of an Edge organization (e.g., no explicit roles or structure). The extent to which behavioural indicators from subjects in the Edge organization matched those in the Hierarchical organization would signal spontaneous adoption of Hierarchical roles by Edge members. On the other hand, the extent to which behavioural indicators in the Edge organization failed to match any found in the Hierarchical organization would signal the formation of Edge-specific role adoption. Subjects in a Hierarchical organization were given explicit instructions on role function. Behavioural indicators were found that effectively clustered members by role (i.e., indicators which grouped Team Members, Team Leaders, and the Cross-team Coordinator into separate clusters). These role-specific indicators were then compared to indicators drawn from members of an Edge organization who were given no explicit role instructions. This paper reports the results of this research which indicate that spontaneous role adoption and self-synchronization can occur in Edge organizations and that the ELICIT platform can be used to assess it.

Introduction

Since its introduction by Cebrowski and Gartska (1998), Network Centric Warfare (NCW) has been the embodiment of many key concepts for transformational change in how modern forces are foreseen to operate in the future. NCW represents a sea change in war-fighting, with several nations adopting NCW like concepts into their transformation, albeit more cautious about including all aspects of NCW (e.g., the Canadian Forces have Network Enabled Operations, or NEOps; Britain has Network Enabled Capabilities, or NEC). The key enabler for NCW concepts is technology that will tie all relevant players into a single information network. Through this network, information exchange will lead to greater shared situation awareness. Greater shared awareness will lead to enhanced agility and effectiveness through self-synchronization. If the linchpin of NCW is the information network, the principle concept, from which enhanced effectiveness and agility is presumed to spring, is self-synchronization. As noted by Alberts and Hayes, "The magic of NCW is the emergence of self-synchronizing behaviour." (p. 2, 2006).

Given its prominence in NCW, it is not surprising that much has been written about self-synchronization. However, far less attention has been paid to validating the concept through controlled experimentation. To be sure, part of this dearth of empirical support lies in the difficulty of executing very high fidelity experiments within a military context. On the other side is the confusion over just what theoretical constructs self-synchronization corresponds to. The concept itself has been assigned many different interpretations and overall remains somewhat vague and elusive (e.g., Van Bezooijen, Essens, & Vogelaar, 2006; see also Araki, 1999). The research reported in this paper was conducted to address some of these concerns and provide needed empirical evidence supporting self-synchronization as an extant behaviour at the operations level.

Self-synchronization

The standard definitions of self-synchronization include four basic characteristics, (a) common/commander's intent, (b) shared awareness, (c) competence, and (d) trust (see Alberts & Hayes, 2003; Cebrowski & Gartska, 1998). However, we prefer to regard these as precursors, enablers, preconditions, or perhaps factors that affect self-synchronization, and instead emphasize the empirical aspects. That is, we prefer to define self-synchronization in terms of its behavioural manifestation when it occurs (i.e., what people actually do) as opposed to its conceptual properties. The result is still the same concept, just a separation into what people do versus what factors have important impact.

There are many ways in which various interested parties have defined and described self-synchronization. The following represents what we feel to be the key aspects. Araki (1999) defines self-synchronization as "… doing the right thing at the right time for the right reason without having to be told by someone higher in the chain of command." (p. 4). Van Bezooijen et al. (2006) take a more pragmatic approach and define the term self-synchronization as referring to "common or shared time" (pp. 3). In a military context, this definition is refined to mean "… the process of coordinating, or orchestrating units on the battlefield." (p. 4). This definition is further refined to include the constraint that the coordinated actions "…create a synergistic effect on combat power" (p. 4) in the sense of creating an effects based outcome. Other definitions of self-synchronization are derived from complexity theory regarding spontaneously behaviours emerging from self-organizing biological systems (e.g., swarming behaviour, Westen, Belenky, & Balkin, 2005).

Individually, what these definitions mean may not be immediately clear. Explicit is the characteristic that coordinated action occurs spontaneously (or at least not require explicit orders to coordinate), and should originate at the level of basic units in the organization. Equally explicit is the claim that mere coordination in time is not sufficient. Coordinated actions should create a force multiplying effect to achieve what is known as an Effects Based Operation (EBO) outcome (Van Bezooijen et al., 2006). Generally speaking, the two principle features of self-synchronization appear to be that actions should occur without explicit direction and be of the sort that creates more effective outcomes than pre-prepared explicitly directed ordered scripts. There are other characteristics but most can be placed into either of these two categories. Some readers may note that one other key feature of self-synchronization is the organizational structure from which self-synchronization is presumed to originate. The typical claim is that unstructured (i.e., flat or edge) organizations are more likely to exhibit self-synchronizing behaviour than more rigidly structured (i.e., hierarchical or stovepipe) organizations.[1]

Given the empirical focus we adopt, the key behavioural aspect of self-synchronization we wish to emphasize is the role each individual plays in the coordinated action. Consistent with this approach, several authors have provided real world examples of self-synchronization (e.g., Alberts & Hayes, 2003; Araki, 1999; Wesensten et al., 2005). One common element in these examples is that self-synchronization manifests itself as individuals with different and distinct roles coordinating their actions to achieve an effects-based outcome. Self-synchronization in these cases seems to be all about individuals coordinating their assigned roles, or possibly adopting new roles, within the context of a team or group action.

The distinction between coordinating roles among team members and spontaneously adopting new roles is a crucial one here. From the discussion on self-synchronization and the anecdotal examples referred to above it is not clear whether people are supposed to just coordinate, or should adopt new ways of acting when self-synchronizing their behaviours. The experiment conducted here was designed to explore the latter of these concepts. Namely, whether people adopt new roles, or roles not explicitly defined for them, when they self-synchronize. Previous research on roles and role adoption in teams provides an empirical basis for the experimentation-based examination of self-synchronization.

Roles and Role Adoption in Teams

The knowledge that team members hold of their own and others' roles is part of the team competencies that are key to effective team performance (e.g., Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995). Waern (1998) defines a role as a "collection of sub-

[1] Although this is clearly an empirical issue, we do not test this hypothesis in this paper.

tasks to be performed by one or several individuals" (p. 13). While more prominent in the multi-agent literature (see e.g., Hexmoor & Zhang, 2001; Vallejos, Ruiz-del-Solar, & Duvost, 2004), role assignment has received limited attention in team research. Indeed, Jentsch, Barnett, Bowers, and Salas (1999) have identified role assignment as one of the team-related variables that require more empirical investigation. Bowers, Urban, and Morgan (1992) have suggested that role assignment – the distribution of responsibilities and information among team members – can have an impact on team performance. The work of Kleinman and Serfaty (1989, cited in Bowers et al., 1992) appears to support this proposition. In a resource allocation task, Kleinman and Serfaty have showed that teams faced with a high-workload situation performed better when there was a partial role overlap between team members, such overlap reducing the probability of errors.

Over the years, team roles have been associated with various factors or constructs related to teamwork, often as an attribute in the description of a broader notion. For instance, task allocation has been defined as the attribution of roles and responsibilities among team members (Breton, Ballas, Barès, Bossé, Foisseau, Jacquart, Jenssen, Kapinus, & Keus, 2004). Similarly, Ioerger (2004) has referred to team structure as "who plays what role". There is in fact a strong link between team roles and organizational structures, as the assignment of roles can determine or be constrained by the organizational structure of the team. Hollenbeck (2000) thus notes that the organizational structure expresses the division of tasks and roles within the structure, among team members. Furthermore, the various ways in which labour can be allocated (and the organizational structures created) will be characterized by different requirements for coordination, communication and the distribution of information (e.g., who needs access to which information; e.g., Stout et al., 1999; Waern, 1998). Fong (2006) also points out that various roles require different levels of information granularity. For instance, a soldier operating at the tactical level will need more detailed information on the terrain and adversary units in close proximity than an officer who needs to manage and plan the operations at a more operational or strategic level.

The explicit assignment of team roles involves a premeditated component, and as such has been identified as a key element of the team planning process (e.g., Stout et al., 1999). Stout et al. have showed that teams that achieve more effective planning have better shared mental models, use more efficient communication strategies, and perform better, especially under high workload. Planning allows the clarification of all team members' roles and responsibilities, which in turn can help team members develop a shared mental model of each other's roles and information requirements, and contributes to improve coordination and performance (e.g., Cannon-Bowers et al., 1995; Stout et al., 1999). In the team development phase, Salas, Sims, and Burke (2005) suggest that team leadership also plays a part in establishing and clarifying team roles. Both at this stage and throughout task execution, a leader will ascertain and maintain a clear knowledge and understanding of each team member's roles (Salas et al., 2005).

Although role assignment can be important during planning, flexibility in team roles is key to allow teams to make adjustments throughout the execution of the task, (e.g., Salas et al., 2005; Waern, 1998). When roles are explicitly assigned, this spontaneous adjustment occurs during the task, for instance in response to unforeseen events and updated information. But in some situations, there is no explicit ‘planned’ organizational structure. Both role assignment and the organization of the team will occur through spontaneous role adoption.

As evident from the above review, much of the research on team roles has empirically confirmed many of the aspects and benefits of self-synchronization described earlier. In particular, the four characteristics defined by Cebrowski and Gartska (1998) are clearly implicated. This supports the use of spontaneous coordination or adoption of roles as a means for how self-synchronization manifests itself. We took this as the basis for our operational definition of self-synchronization and the subsequent experiment. To that end, we chose a research tool specifically designed to test NCW/NEOps concepts.

The ELICIT Team Experimentation Platform

NCW or NEOps concepts have been developed in a context that emphasizes the importance of organizational structure and its relationship to team effectiveness (e.g., Alberts & Hayes, 2003). The distinction between hierarchical and flat organizations is a central theme of NCW/NEOps concepts and follows from research conducted at the Command and Control Research Program (CCRP). In order to help validate NCW/NEOps concepts in general, and hypotheses about the relative effectiveness of edge organizations compared to other organizational structures in particular, an experimentation platform was required. Ideally, these measures should be captured in a real-time experimental situation involving different types of intra-organizational interactions. In response to the need for a suitable research tool, Parity Communications Inc. (2006b) developed an operations level team experimentation platform. The platform, called the Experimental Laboratory for Investigating Collaboration, Information Sharing and Trust (ELICIT) was designed to test hypotheses about the effectiveness of edge organizations.

ELICIT is designed around a simple problem solving task in which team members must acquire information to answer a four part question (who, what, when, where) concerning an impending adversary attack. All information about the attack is represented as brief descriptive statements called factoids which describe the who, what, when, and where. For each answer there are several possible alternatives (e.g., 8 possible terrorist groups). The goal for answering each question is to learn the alternatives and eliminate all but the correct one. Because there is only one correct alternative for each question part, factoids imparting information that supports the correct alternative can be considered key, expert or supportive (collectively called “signal”) factoids, whereas factoids about incorrect alternatives are considered “noise”.

Participants can acquire information in two main ways; either from the system itself or from other players. Information from the system comes in the form of injects which occur several times at the start of a trial run. The primary means of acquiring information however is from other players. This is done through peer-to-peer (p2p) sharing of factoids or by posting factoids to various bulletin boards which can be viewed by other players. The way in which factoids are originally distributed via injects requires that players share information to find answers to all four parts of the question. That is, no player is provided with enough information to answer the questions at the start.

Because of the restricted environment, there is a fixed number of actions that each subject can engage in. Whenever a subject performs an action, that event is logged. Subjects spend the bulk of their time in the problem solving task either sending, receiving, or evaluating factoids. At present, the system is designed to run two different organizational structures. One is a hierarchical stove-pipe structure with predefined roles and explicit chain of command. The other is a completely non-structured organization (flat or edge) with no explicit roles defined for players.

Rationale and Experiment

The purpose of this experiment was to provide support for self-synchronization as spontaneous role adoption within the ELICIT team platform. We focused on both the spontaneous (in which team members act without specific top-down direction) and the enhanced effectiveness (effects-based) aspects of self-synchronization. The approach taken was to observe the emergent behaviours that arise from spontaneous role adoption by comparing subjects who were given specifically defined roles to those who where given no role specific instruction about roles. This was done by assigning players in one condition (C2) to specific roles with very clear instructions about duties and goals. Players in the other condition (Edge) were not assigned to roles or given any such instructions regarding specific duties and goals. For the analysis, roles were operationally defined as the specific response frequency pattern of actions taken while using in the ELICIT platform (see results section for details). Self-synchronization was operationally defined as the spontaneous adoption of roles by subjects in of the Edge condition. Effectiveness was operationally defined to be the proportion correct answers to the four part question. In accordance with the assumptions of self-synchronization outlined above, we hypothesize (a) that subjects in the Edge condition will spontaneously adopt C2 roles and (b) that spontaneous adoption will lead to better effectiveness.

Subjects

A total of 34 subjects were paid for their participation in this study. Seventeen subjects were randomly assigned to each condition. All subjects were civilian employees of DRDC Toronto, computer literate, and had no previous experience with the ELICIT platform. To ensure anonymity, all subjects were assigned an arbitrary alias used to identify them within the ELICIT system.

Conditions

Two conditions were run in the experiment. The conditions differed with respect to the role-based organization imposed on the players. In one condition (C2), players were divided into four sub-teams of four. Each sub-team consisted of two types of role: One Team-leader and three Team-members. Each sub-team was told that they were responsible for answering only one of the questions (e.g., who, what, when, or where). The seventeenth subject was assigned to be the Crossteam-coordinator. This subject was told to answer all four parts to the question. Each of the three roles (Team-member, Team-leader, Crossteam-coordinator) were defined by specific instructions about expected duties and goals to be achieved. For Team-members, these instructions were:

> The role of the Team Member is to send information you receive about the adversary attack to the Team Leader, and to figure out the answer to the question assigned to your team.

For Team-leaders, these instructions were:

> The Team Leader receives special information about the adversary attack and is responsible for making sure all team members are provided with all relevant information for the question the team has to answer, as well as trying to figure out the answer to the question assigned to your team.

For the Cross-team Coordinator, these instructions were:

> The role of the Cross-team Coordinator is to coordinate the flow of information between the 4 teams that is relevant to the question the team is responsible for answering. In addition, the Cross-team Coordinator has the responsibility to answer all 4 questions about the adversary attack.

In the other condition (Edge), no organizational structure was imposed on the players. In addition, subjects in the Edge condition received no explicit instructions about particular roles or responsibilities. Instead, they were told their only goal was to determine the answer to all four parts of the question.

In both conditions, subjects were given instructions about how to use the software, the nature of factoids, and that the general goal of the task was to find answers to the four parts of the question.

Methods and Procedure

The experiment itself of a single testing session; comprising instructions, pre-questionnaire, practice, experiment, post-questionnaire, and debrief phases. For the instruction phase, participants were shown an instructional video describing the problem solving task along with a demonstration of the software. They were also given instructions relevant to the experimental condition in which they were participating. Following the instructions, subjects were given the opportunity for questions. All subjects were then given the Trust in Teams scale (Adams & Sartori, 2006), and subject in the C2 condition were also given the Team Leadership scale (Adams & Sartori, 2006). These scales took approximately 5 min to complete. Subjects then participated in a 20 min practice trial followed by a 60 min experimental trial. Execution of the software platform was identical for both the practice and experimental trials. When there was approximately 5 minutes left in the practice or experiment phases, participants were informed they had 5 minutes left to submit answers if they had not already done so. Once the practice or experiment phase ended, activity between computers was halted and the participants were informed of the correct answer.

At the start of the practice and experiment phases, 2 factoids were distributed to each participant. After 5 min another factoid was sent to each participant followed by a third inject 5 min after that. In between factoid injects, participants were free to send/receive/post/retrieve factoids in an attempt to answer the question or questions assigned to them. Whenever a participant felt they knew an answer to a question, they could submit their answer using the software. Participants were allowed to submit answers as often as they wished during a trial. During practice, subjects were free to ask questions and experiment with the software. There were also given scratch paper to jot down notes. Once the practice trial ended, subjects were given a final opportunity to clear up any questions before commencing the experimental trial. During the experimental trial subjects were free to solicit the help of the experimenters, but were not permitted to speak to each other. Old scratch paper was removed and a new set of scratch paper was given to each subject. Once the experimental trial was complete, subjects were once again given the Trust in Teams scale, and for subjects in the C2 condition, the Team Leadership scale. A questionnaire developed specifically for ELICIT was then given to all subjects (Parity, 2006a). After finishing the questionnaires, subjects were shown a short debriefing video.

Table 1. List of actions permitted in the ELICIT team experiment platform.

Action	Description
Push	Posting a factoid to a global bulletin board website.
Pull	Retrieving a factoid from a global bulletin board website.
Share	Sending a factoid to another player.
Receive	Receiving a factoid sent by another player.
Identify	Submitting answers to one or more part of the question.
What_see	Examines the roles of other players and overall team structure.
How_seen	Examines own role and place in overall team structure.

Results

For the data analysis, role categories were identified in the C2 condition using a cluster analysis based on a response frequency matrix. Subjects in the Edge condition were then mapped onto the role categories identified in the C2 condition. Subsequent analysis of behavioural indicators was conducted to validate the assignment of Edge players into the various role categories identified in the C2 condition.

Role Cluster Analysis

Table 1 lists the six possible actions that players can execute within the ELICIT platform, along with a seventh action added by the experimenters. A sequential action paired-associate response frequency matrix was computed for each subject by counting the frequency with which a given action was followed by every other action including itself. A sequential action paired-associate response frequency matrix was used because it was thought that better behavioural identification of specific roles would be achieved based on how actions chained together as opposed to simple response frequencies. Table 2 shows an example of one subject's paired-associate response frequency data.

Table 2. Example of sequential action paired-associate frequency matrix for subject in the C2 condition. Rows correspond to the initial action whereas columns refer to the subsequent action.

	Push	**Pull**	**Share**	**Receive**	**Identify**	**What_see**	**How_seen**
Push	3	6	3	2	0	1	0
Pull	7	107	12	18	4	6	4
Share	1	17	7	2	0	2	0
Receive	4	11	4	13	3	1	0
Identify	0	7	0	0	1	0	0
What_see	0	11	0	0	0	0	1
How_seen	0	0	0	0	0	4	0

C2 Clusters. The paired-associate response frequency matrix for each subject in the C2 condition was submitted to a hierarchical cluster analysis to determine whether subjects would cluster according to their originally assigned roles. Clustering was done by maximizing a between-subjects Chi-squared proximity metric. The number of clusters was increased until each of the original assigned role types was situated in separate clusters. Note that this does not preclude clustering of like roles. Using this method required a minimum of six clusters. Although other methods produced similar results, this combination required the fewest number of clusters to separate out the originally assigned roles. The results of the cluster analysis are given in Table 3. As can be seen in the table, three groups of Team Leaders emerged along with two groups of Team Members, and the Cross-team Coordinator as a single group.

Table 3. Results of cluster analysis for the C2 condition. Columns define the cluster category. Note: CTC=Cross-team Coordinator, uppercase 'L' refers to a Team Leader.

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
CTC	Where_L	Who_L	What_L	When	When
			When_L	When	Who
				Who	What
				Who	What
					What
					Where
					Where
					Where

Edge Clusters. Edge condition subjects were added to the clustering data set and the algorithm rerun. When the same criteria for determining number of clusters were applied, a total of six clusters was required. Table 4 shows how Edge subjects were distributed among the identified clusters. Note that subjects in the C2 condition separated into the same sets of clusters. Also note that the Edge subjects fell into only two of the groups, that occupied by C2 Team Members and that occupied by the Cross-team Coordinator. This despite pushing the number of clusters to six.

Three main results came out of the cluster analysis. First, the initial clustering divided subjects in the C2 condition into categories representing the distinct roles that subjects were assigned to in that condition. Second, when Edge subjects were added to the dataset, those subjects were associated with only two types of explicit roles, Team Members and the Cross-team Coordinator. Third, subjects in the Edge condition did not form a cluster unique only to subjects in that condition. That is, there was no evidence that Edge subjects adopted an Edge specific role.

Validating Role Clustering

To support the grouping of C2 and Edge subjects into the respective clusters, a set of behavioural indicators were used to confirm the similarity of subjects within clusters. The behavioural indicators used to compare Edge and Hierarchical organizations were the proportion of reciprocated shares and the proportion of each type of actions (e.g., pull, post, share). For these behavioural indicators data were analyzed by role, either explicitly defined as in the C2 condition, or those identified by the cluster analysis as spontaneously adopted in the Edge condition. The ID score was used to compare performance in the two organizations.

Table 4. Results of cluster analysis when both conditions were included in dataset. Note: CTC=Cross-team Coordinator, uppercase 'L' refers to a Team Leader.

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
CTC	Where_L	Who_L	What_L	When	When
Edge			When_L	When	Who
Edge				Who	What
Edge				Who	What
Edge					What
Edge					Where
					Where
					Where
					Edge
					Edge
					Edge
					Edge
					Edge
					Edge
					Edge
					Edge
					Edge
					Edge
					Edge
					Edge

Proportion of Reciprocated Shares. When analyzed as a function of the role of sender, the proportion of reciprocated shares revealed a different pattern in the C2 and Edge conditions (see Table 5). In the former, a greater proportion of shares were reciprocated when originating from an "authority figure" (Cross-team Coordinator or Team Leader).

Conversely, reciprocated shares were not more frequent when shares came from someone who spontaneously took on an authority or leadership role (Cross-team Coordinator cluster) in the Edge condition.

However, if examined based on the role of the receiver, the proportion of reciprocated shares showed a similar pattern in the Edge and C2 conditions (see Table 6). That is, in both conditions shares were reciprocated more frequently when the person receiving a share fulfilled a leadership role.

Table 5. Proportion of reciprocated shares in the C2 and Edge conditions conditional on the sender. Edge conditions refer to players clustered with the Cross-team Coordinator (Cluster 1) or other C2 players (Cluster 6).

Condition	Mean	Std Error
Edge		
Cross-team Coordinator	.38	.07
Team Member	1.00	0
Hierarchical		
Cross-team Coordinator	.90	.10
Team Leader	.64	.10
Team Member	.36	.06

Table 6. Proportion of reciprocated shares in the C2 and Edge conditions conditional on the receiver. Edge conditions refer to players clustered with the Cross-team Coordinator (Cluster 1) or other C2 players (Cluster 6).

Condition	Mean	Std Error
Edge		
Cross-team Coordinator[2]	.94	.056
Team Member[3]	.21	.07
Hierarchical		
Cross-team Coordinator	1.00	0
Team Leader	.37	.08
Team Member	.5	.08

Proportion of Actions. Analysis of the types of actions taken by participants throughout the execution of the task indicated that for the three main information exchange actions

[2] Edge subjects assigned to Cluster 1.
[3] Edge subjects assigned to Cluster 6.

(pull, post, and share), slight differences appeared between the two conditions. Particularly, participants in the Edge condition pulled information from the websites more frequently than participants in the C2 condition, and also did fewer shares. The proportion of posts was similar in the two conditions.

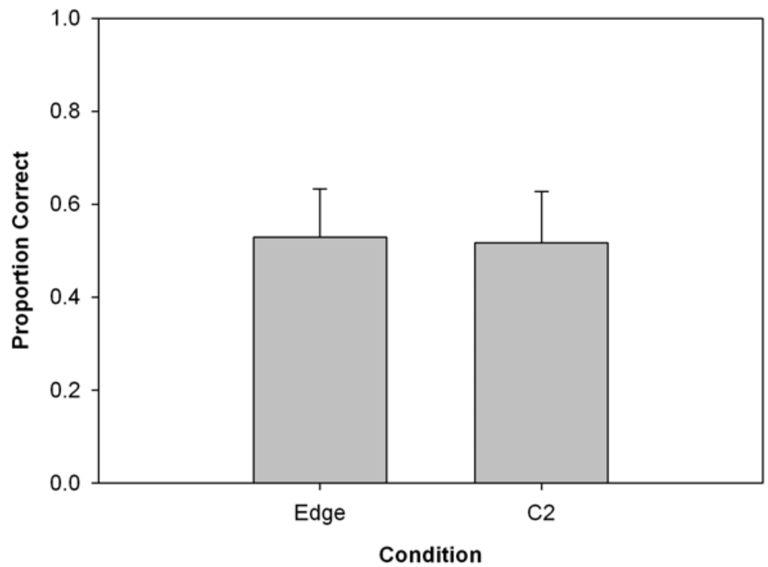
An analysis of the proportion of actions by role (explicit and adopted) revealed a similar pattern of behaviour in the C2 and Edge conditions. Participants who spontaneously took on a Cross-team Coordinator or Team Member role in the Edge condition generally acted like their respective counterparts in the C2 condition. Likewise, subjects who were assigned team member roles were more like those who spontaneously adopted that role. For instance, in both conditions team members did more pulls than Cross-team Coordinators, while the latter did more shares. Statistically however, the difference between the assigned and adopted Cross-team Coordinator role was very close to significance, $\chi^2(5)=11.07$, $p<.06$. For the assigned and adopted Team Member roles, a similar results was found, namely, both groups close to showing significant differences, $\chi^2(5)=9.70$, $p<.09$. These data are given in Table 7.

***ID Score*.** Team performance in the Edge and C2 conditions was assessed through the ID score. This normalized score was computed using the last answer for each of the four questions (i.e., who, what, where, when) in the Edge condition, and the one question that participants had to answer in the C2 condition (e.g., who for the Who team, where for the Where team). An analysis of variance was conducted on the ID score, with condition as a between-subject factor. The proportion correct for each condition was .52 and .53 for the C2 and Edge conditions respectively (see Figure 1). Not surprisingly, the analysis revealed no significant difference in performance between the conditions, $F<1$. Clearly, subjects in the two conditions were equally capable of identifying the details of the fictitious terrorist plot, with both groups well above chance.

Table 7. Proportion of actions taken by subjects who were either assigned roles (C2 condition) or who adopted those roles (Edge condition). Note: CTC=Cross-team Coordinator, TM=Team Member.

Condition	Action					
	Pull	Post	Share	What See	How Seen	ID
Edge						
CTC	.60	.05	.24	.05	.03	.04
TM	.78	.05	.02	.08	.04	.03
C2						
CTC	.48	0	.41	.06	.01	.03
TM	.63	.04	.13	.13	.05	.03

Figure 1. Proportion of correct answers given for the C2 and Edge conditions. Only the last answer submitted for the C2 group, or the last answer for each part in the Edge group, were used in scoring responses.



Discussion

From the cluster analysis it was found that subjects in the Edge condition spontaneously adopted either the Cross-team Coordinator role or Team Member role from the C2 condition. Comparison of proportion of reciprocated shares and proportion of actions between subjects with adopted and assigned roles suggested that roles spontaneously adopted by subjects in the Edge condition were similar to the corresponding assigned roles of the Hierarchical condition. Thus, despite a complete lack of explicit direction for how to conduct and coordinate their actions to solve the problem, subjects in the Edge condition spontaneously adopted two types of distinct roles, a coordinator role (Cross-team Coordinator), and a general worker role (Team Member). The other explicit roles were not considered by Edge subjects.

The possibility that Edge subjects might nonetheless be showing indications of Team Leader roles seems unlikely as the C2 role specific clusters (clusters 2-5) were the first to split from the main group in the cluster analysis that included all subjects. On the other hand it is possible that a different set of behavioural indicators might lead to a different clustering. This is indeed possible as cluster analysis is completely determined by the descriptor variables used to compute the distance/similarity metrics. The only justification we can offer is that the sequential action paired-associate matrix behavioural indicator is a better descriptor of role than mere action frequency distribution because it takes into account both how actions were executed in relation to each other in addition to what actions where made (i.e., the distribution of overall action frequency is implicit in the paired-associate matrix).

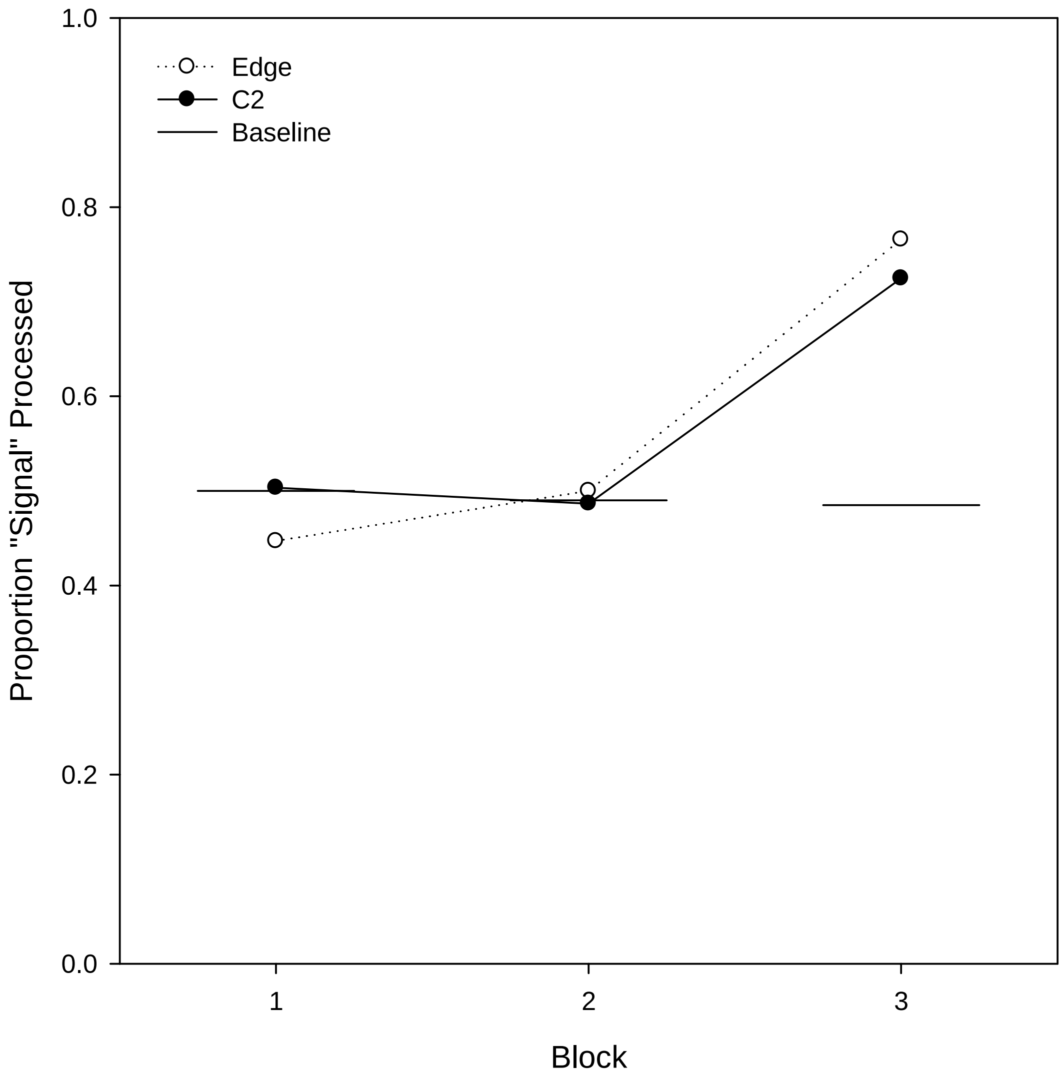
The one hypothesis concerning self-synchronization that was not supported at all by the data was performance. Although both groups were equally effective and well above chance in answering the questions, both were also identical in at least one measure of performance. The proportion of signal factoids actioned by subjects (i.e., sent, received, pushed, etc) did not differ between conditions. Early on in the trial there was no evidence that signal factoids were being selected out for attention over noise factoids. This is to be expected as participants would not have any context for deciding which bits of information are relevant. However, by well into the trial (third block) subjects in both conditions were selectively manipulating signal factoids at the expense of noise factoids at a rate well above chance (see Figure 2).

Conclusions

Overall, the evidence supports some assumptions of self-synchronization. Subjects in the Edge condition showed spontaneous adoption of roles specified in the C2 condition, but did not spontaneously adopt any novel roles. Other effects failed to materialize altogether (i.e., differences in effectiveness). Although this could reflect the nature of self-synchronization, the results could also be due to limitations of the ELICIT platform. In ELICIT, subjects can only share or post factoids which restricts the range of possibilities for communication. Given the restricted means for interacting with other players, there may not have been sufficient flexibility within the platform for subjects to express a wider array of behaviours. This would explain why when subjects were left to their own devices (i.e., Edge condition) they chose to emulate only a few possible roles. Of equal importance is the fact that there were no task constraints in the Edge condition that obviated the need for more complex behaviours. This explains why subjects in the Edge condition failed to adopt any Edge-centric roles.

On the other hand, organizational differences between conditions can explain why Edge subjects failed to adopt all C2 roles. Restrictions on website access in the C2 condition necessitated the sharing of factoids between teams. In the Edge condition where all subjects have unrestricted website access, there is little need to share factoids at all. This could explain why the Team Leader role was not adopted by subjects in the Edge community. The implication of this result is that changes to the communication structure of a team (global vs. local information access) can cause some roles to become superfluous. This conclusion must be tempered by the fact that there were no differences in both performance and effectiveness between the conditions. In terms of roles, the only difference between the conditions was the presence of the Team Leader role. This implies the role of Team Leader contributes nothing to overall team performance and effectiveness within the ELICIT platform regardless of team structure. In fact, more detailed analysis of effectiveness revealed that the Team Leader role showed the least discrimination between signal and noise factoids.

Figure 2. Proportion of "Signal" factoids processed across blocks 1-3 for the C2 and Edge conditions.



In conclusion, these results provide some support for use of the ELICIT platform in research of NCW/NEOps concepts like self-synchronization. But some caution is warranted. The platform is capable of demonstrating some aspects of self-synchronization, but the results were also clearly determined by characteristics of the platform itself. Hence, the results show limitations of the platform as well as constraints of the self-synchronization concept. Further experimentation is certainly warranted to explore other aspects of role adoption and within ELICIT, but this would seem to necessitate changes to the platform. Most notable would be to allow for communication of information besides just factoids. This could take the form of (a) guesses about the answer to each question, (b) requests for information on specific questions, (c) assessments about the relevance of factoids.

References

Adams, B. D., & Sartori, J. (2006). *Validating the Trust in Teams and Trust in Leader Scales*. (Defence Research and Development Canada Rep. No. CR-2006-008). Toronto, ON: Defence Research Development Canada.

Alberts, D. S., & Hayes, R. E. (2003). *Power to the edge: Command… control… in the information age*. Washington, DC: CCRP Publications.

Alberts, D. S., & Hayes, R. E. (2006). *Understanding command and control*. Washington, DC: CCRP Publications.

Araki, L. M. K. (1999). *Self-synchronization: What it is, how it is created, and is it needed?* (Naval War College Rep. No. 19990520 069). Newport, RI: Naval War College.

Van Bezooijen, B. J. A., Essens, P. J. M. D., & Vogelaar, A. L. W. (2006). *Military self-synchronization: An exploration of the concept*. Paper presented at the 11th Annual Command and Control Research and Technology Symposium, Cambridge, UK.

Bowers, C. A., Urban, J. M., & Morgan, B. B. Jr. (1992). *The study of crew coordination and performance in hierarchical team decision making* (Team Performance Laboratory Rep. No. 92-01). Orlando, FL: University of Central Florida.

Breton, R., Ballas, J., Barès, M., Bossé, E., Foisseau, J., Jacquart, R., Jenssen, A., Kapinus, R., & Keus, H. (2004). *Modelling of organisations and decision architectures*. Final report of NATO RTO/IST-019/TG006.

Cannon-Bowers, J. A., Tannenbaum, S., Salas, E., & Volpe, C. (1995). Defining competencies and establishing team training requirements. In R. Guzzo & E. Salas (Eds.), *Team effectiveness and decision making in organizations*. San Francisco, CA: Jossey Bass.

Cebrowski, A. K., & Gartska, J. J. (1998). Network centric warfare: Its origin and future. *Proceedings Magazine, 124,* 1.

Fong, G. (2006). Adapting COTS game for military experimentation. *Simulation & Gaming, 37*(4), 452-465.

Hexmoor, H., & Zhang, X. (2001). Norms, roles, and simulated RoboCup. In 2nd *Workshop on Norms and Institutions in Multiagent Systems (Agents 2001)* (pp. 35-42). Montreal, Canada: ACM press.

Hollenbeck, J. R. (2000). A structural approach to external and internal person-team fit. *Applied Psychology: An International Review, 49*(3), 534-549.

Ioerger, T.R. (2004). Reasoning about beliefs, observability, and information exchange in teamwork. *Proceedings of the Seventeenth Florida Artificial Intelligence Research Society Conference* (FLAIRS'04).

Jentsch, F., Barnett, J., Bowers, C. A., & Salas, E. (1999). Who is flying this plane anyway? What mishaps tell us about crew member role assignment and air crew situation awareness. *Human Factors, 41*(1), 1-14.

Kleinman, D. L., & Serfaty, D. (1989). *Team Performance assessment in distributed decision-making*. Paper presented at the Simulation and Training Research Symposium on Interactive Networked Simulation for Training, University of Central Florida, Orlando, FL.

Parity Communications Inc., P. C. (2006a). *Experiments in command and control within edge organizations*. (Contractor Rep. No.) Chestnut Hill, MA: Parity Communications Inc.

Parity Communications Inc., P. C. (2006b). Experimental Laboratory For Investigating Collaboration, Information-Sharing, And Trust (ELICIT) [Computer Software]. Chestnut Hill, MA: Parity Communications Inc.

Salas, E., Sims, D. E., & Burke, C. S. (2005). Is there a "Big Five" in teamwork? *Small Group Research, 36*(5), 555-599.

Stout, R. J., Cannon-Bowers, J. A., Salas, E., & Milanovich, D. M. (1999). Planning, shared mental models, and coordinated performance: An empirical link is established. *Human Factors, 41*(1), 61-71.

Vallejos, P. A., Ruiz-del-Solar, J., & Duvost, A. (2004, October). Cooperative strategy using dynamic role assignment and potential fields path planning. 1st IEEE Latin American Robotics Symposium – LARS 2004 (pp. 48-53), Mexico City, Mexico.

Waern, Y. (1998). Analysis of a generic dynamic situation. In Y. Waern (Ed.), *Cooperative process management: Cognition and information technology* (pp. 7-20). London, England: Taylor and Francis.

Westen, N. J., Belenky, G., & Balkin, T. J. (2005). Cognitive readiness in network-centric operations. *Parameters, Spring*, 94-105.