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Role Allocation and Team Structure in Command and Control Teams

Topic 4 (Primary)
Experimentation, Metrics, and Analysis

Topic 2
Organizational Concepts and Approaches

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Defence and security organizations are increasingly faced with uncertain and dynamic global security environments. Often highly structured in nature, command and control (C2) in these organizations may not traditionally allow for the adaptability and flexibility required in these complex situations. In response, models of more agile, decentralized organizations – such as Edge organizations – have been proposed. To further the understanding of these organizations and their potential benefits and limitations, we sought to examine how edge-like teams spontaneously adopt and organize roles when engaging in complex, collaborative activities in the context of crisis management situations. A forest firefighting simulation was used to compare functional (explicitly assigned roles) to edge-like (no assigned roles) organizations. Four-person teams completed scenarios characterized by the occurrence of sudden and critical events. Behavioural indicators associated with various roles in the simulation (e.g., operations, resources management, search and rescue) were measured, and we assessed the extent to which these indicators matched when comparing functional teams to edge-like teams. A behavioural indicator matching across the two conditions would indicate that edge-like teams adopted a similar structure as functional teams. The results suggest edge-like teams allocate role differently from functional teams, but for a given team that allocation remain relatively stable once established. The findings are discussed with regards to team effectiveness and agility in complex C2 environments.

Introduction

Defence and security organizations are increasingly faced with uncertain and dynamic global security environments, which are ever more ill-defined, unpredictable, and time pressured. Often highly structured in nature, command and control (C2) in these organizations may not traditionally allow for the adaptability and flexibility required in these complex environments. In response, models of more agile, decentralized organizations – such as Edge organizations (EO) – have been proposed (e.g., Alberts & Hayes, 2003, 2006). These organizations are described as adaptive, promptly reconfigurable, and highly distributed. EO themselves are at the very end of the continuum as highly decentralized, self-synchronizing, and fluid organizational structures (Alberts & Hayes, 2006). Conceptualized at both the organizational and team levels, EOs are assumed to be more responsive and to provide the agility to adapt to emerging situations and contingencies without preplanning and hierarchical direction. Self-organization and self-synchronization are considered key capabilities of EOs, and performance in such organizations is thought to be directly related to their capacity for agility (Alberts & Hayes, 2006). Notions akin to EOs date back about 30 years. For instance the organizational psychology and management sciences literature show concepts such as empowered self-management and self-regulating work teams (see Cooney, 2004, for a review). While the concept of a fully decentralized organization put forward in EOs is likely not achievable or, arguably, desirable for military and security organizations, there is a need for increased flexibility and agility to deal with the challenges of the current and future security environments.

At the team level, one particular aspect of interest for agility is role allocation. A role can be defined as a set of tasks to be carried out by one or more person (Waern, 1998). Role allocation therefore refers to the distribution of tasks, responsibilities, and resources (e.g., information) among team members (e.g., Bowers, Urban, & Morgan, 1992; Breton et al., 2004). Flexibility in team members' roles could enable a team to adapt to varying levels of workload by supporting each other's roles and shifting tasks (e.g., Huey & Wickens, 1993) or to respond to unexpected events by self-synchronizing and creating new roles or adapting existing ones (e.g., Araki, 1999; Wesensten, Belenki, & Balkin, 2005) all with the aim of achieving the team's mission. Role allocation has been investigated in the context of agility and adaptability for at least a decade (e.g., Burke, Stagl, Salas, Pierce, & Kendall, 2006; Dubé, Tremblay, Banbury, & Rousseau, 2010; Jobidon, Labrecque, Turcotte, Rousseau, & Tremblay, 2013; LePine, 2003). Theoretical and empirical work has also suggested relationships between role allocation and other key aspects of teamwork, such as planning (e.g., Stout et al., 1999) and leadership (e.g., Salas, Sims, & Burke, 2005). Explicit role allocation enables team members to develop an understanding of their own and others' roles and responsibilities, and has been shown to be associated with enhanced team planning process, shared situation awareness, and overall team performance (e.g., Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995).

By definition, role allocation is closely linked to organizational or team structure. Indeed, Ioerger (2004) described team structure as "who plays what role". The relationship between role allocation and structure can be considered bidirectional. In one way, organizational structure can result from requirements with regards to coordination, communication, and distribution of information and resources. In another way, the structure can also dictate or constrain the allotment of tasks, responsibilities, and resources among team members (e.g., Fong, 2006;

Hollenbeck, 2000; Waern, 1998). In C2 contexts, the organizational structure is often hierarchical (e.g., in military organizations) or functional (e.g., in security or crisis management organizations) in nature. In both cases, roles are assigned a priori and explicitly to team members. This is the case of FIRESCOPE (Office of Emergency Services, 2007), a crisis intervention plan used by several emergency services in the United States. Despite the importance of explicit roles, teams need to be able to adjust their roles during the execution of their mission in order to deal with the changing demands and unpredictability of dynamic and complex environments (e.g., Rousseau, Aubé, & Savoie, 2006; Salas et al., 2005).

Role adjustment during the course of a mission can be accomplished with various levels of planning and preparation. As mentioned previously, different organizational structures can enable different distributions of tasks and resources among team members, with more or less flexibility. Also, depending on the culture and doctrine of a given military or security organization, varying degrees of overlap and cross-training (i.e., more generalist vs. more specialized roles) can exist, allowing team members to use back-up behaviours (Rousseau et al., 2006; Salas et al., 2005) and online task balancing (e.g., Jobidon, Tremblay, Lafond, & Breton, 2006) as means to adjust to changing events and workload. Self-synchronization is at the ad hoc end of the spectrum, where teams take coordinated action without explicit direction and with more effective outcomes than preplanned actions (e.g., Duncan & Jobidon, 2008; van Bezooijen, Essens, & Vogelaar, 2006). Regardless of the degree of planning involved, one common element to concepts such as cross-training and self-synchronization is the notion of sharing roles, tasks, information or resources with more or less flexibility and overlap across team members.

However, role ambiguity is a potential drawback of having the flexibility of adjusting or creating roles during the execution of a mission. Lack of clarity regarding team members' roles and responsibilities can act as a major hindrance to performance (e.g., Klein et al., 2009; Lepine, Lepine, & Jackson, 2004). Spontaneous reorganization or adoption of roles may increase agility. However, whether changes to allocated roles and role adoption is beneficial remains to be determined, as do the conditions or threshold under which the potential hindrance of role ambiguity becomes organizational flexibility that can make a military or security team more efficient and responsive (see Alberts & Nissen, 2009).

Purpose of the Study

To further the understanding of flexible organizations and their potential benefits and limitations, we sought to examine how edge-like teams spontaneously adopt and organize roles when engaging in complex, collaborative activities in the context of crisis management situations. We compared functional (role-specific) teams to edge-like teams for which no roles or tasks were assigned. Team members had to determine how to allocate roles, task, and resources, and how to go about completing their mission. We sought to investigate the extent to which edge-like teams organize differently from functional teams and whether they take advantage of the flexibility afforded by the lack of structure to modify role allocation throughout various missions, in response to changes in the environment.

Method

Participants

Participants were 192 volunteers recruited on the Université Laval campus in Québec City, Canada (114 women and 78 men; *M* = 25.2 years old, *SD* = 8.7 years). Participants were randomly assigned to 48 four-person teams. Participants received a monetary compensation of $25 CAD in exchange for their participation.

Material

The study's task environment was the C^3Fire microworld, a computer-based simulation of forest firefighting (e.g., Granlund, 1998, 2003; Tremblay, Lafond, Gagnon, Rousseau, & Granlund, 2010; Tremblay, Lafond, Jobidon, & Breton, 2008). The C^3Fire interface contains a geospatial map, displayed on a 40 × 40 cell grid, built up by a set of four interacting simulation layers: fire, geographical objects, weather, and intervention units (see Figure 1).

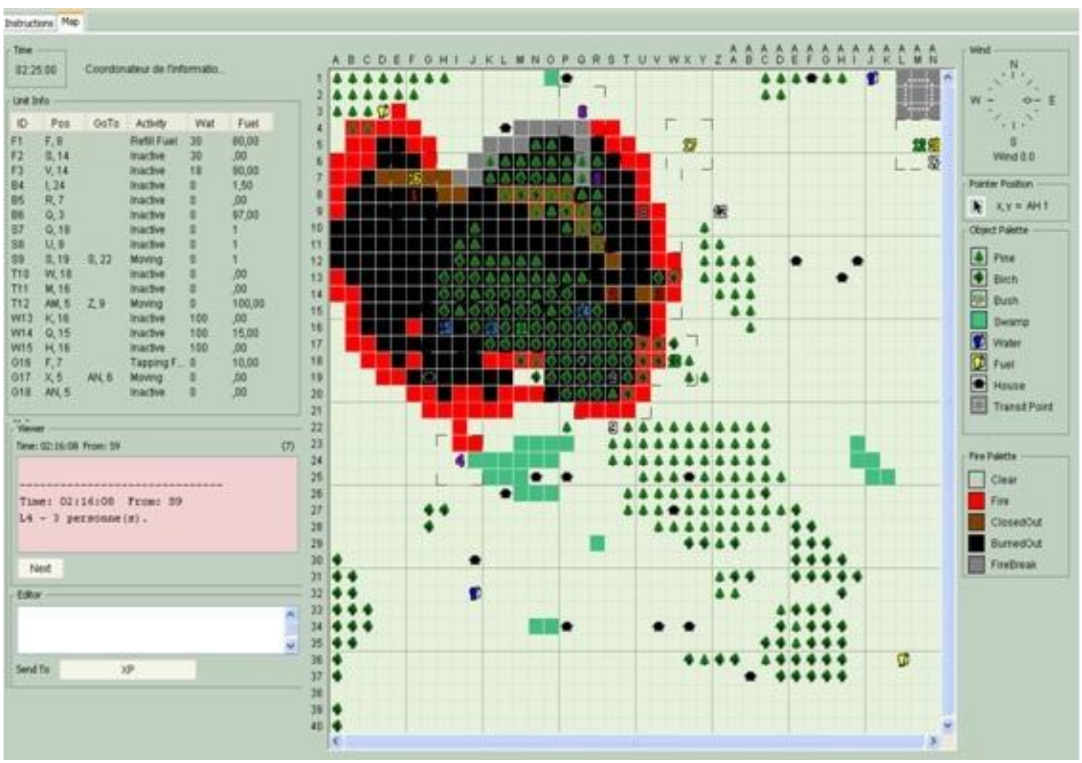

Figure 1. C^3Fire interface.

The first two layers define the dynamics of the environment. The *fire* layer outlines five different states for each cell of the map: clear, built with a firebreak, on fire, extinguished, or burnt out. A clear cell corresponds to a cell in which no fire has started yet, but that could be ignited if a bordering cell is on fire. A cell becomes red when it ignites and is burning, and brown when extinguished by firefighters. If a cell is not extinguished within a set time period after ignition, it burns out and turns black. A burnt-out cell cannot be extinguished or reignited. If a firebreak is built on a clear cell, that cell turns grey and can no longer catch fire. The *weather* layer determines the strength and direction of the wind, which directly influences the spread of the fire. The stronger the wind, the faster the fire spreads to adjacent cells in the same direction as the wind blows.

The last two layers characterize the content of the geospatial map. The *geographical objects* layer defines the various physical objects or features displayed on the map (e.g., houses, transit point, water tanks, fuel tanks, types of trees, and swamps). The content of a cell determines the time it takes to ignite (e.g., birches can be set to catch fire more quickly than houses). In this study, swamps, transit point, water tanks, and fuel tanks could not ignite. The *unit* layer outlines the types of intervention units controlled by the participants. There are six types of units: firefighter (FF), firebreakers (FB), water tankers (WT), fuel tankers (FT), search units (S) and rescue units (R). Each unit is represented on the map by a numbered icon. Each type of unit is colour-coded and fulfills a specific role: FF extinguish fire, FB create firebreaks to control the spread of fire, FT and WT supply water and fuel 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 safety at a transit point.

To move a unit on the map, a participant clicks on the unit and drags it to the desired location. FF extinguish fire by moving to a burning cell, which empties their reservoir at a predetermined rate. Their reservoir contains a limited quantity of water, and they can be refilled by moving a WT to a cell adjacent to the FF. Similarly, FF, FB, WT, and R have a limited fuel tank, which is refilled by moving a FT to an adjacent cell. Finally, both WT and FT have a limited reservoir to hold their respective resources, and have to be refilled by moving the unit to water and fuel tanks, respectively, distributed on the map.

For each C^3Fire scenario teams completed as part of this experiment, every event in the microworld (e.g., a cell igniting or burning out, keystrokes) as well as continuous screen capture was recorded using the Morae software (TechSmith, Okemos, MI). Team members communicated verbally with each other via headsets, by holding down the Control key on the keyboard. Teamspeak (TeamSpeak Systems, Krün, Germany) was used to transmit and record all communications.

Design

The study design was a 2 (team structure) × 2 (time pressure) × 2 (workload) mixed design. The between-subject variable was team structure (functional, edge-like), and the within-subjects variables were time pressure and workload. For the purpose of this study and within the C^3Fire environment, time pressure was defined as the tempo at which the fire spreads (slow, fast) and workload was operationalized as the number of fires teams have to manage simultaneously (one or two fires). As presented in Table 1, the combination of the two within-subjects variables created the four test scenarios, each characterized by different dynamics. The order in which teams completed the scenarios was counterbalanced.

Table 1. Combinations of the two independent variables in each test scenario.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Tempo	slow	slow	fast	fast
Fires	two	one	one	two

Procedure

Teams were assigned randomly to one of two team structure conditions: functional or edge-like. In the functional condition, participants were randomly allocated to one of four roles: *operation chief*, responsible for three FF and three FB; *search and rescue chief*, in charge of three R and three S; *resources management chief*, responsible for three WT and three FT; and *planning chief*, who did not control any units but saw the position and the information about the units of his or her team members. The planning chief was required to send a message to the media every two minutes to give a situation report about the propagation of the fire and the rescue of civilians. In the edge-like condition, information on the different units was provided to participants, and they were instructed to allocate the roles and the units amongst themselves as they saw fit. Participants had to achieve three goals: 1) to save civilians in houses from the fire, 2) to prevent houses from burning, and 3) to limit fire spread.

The overall study lasted between 2.5 and 3 hours. Figure 2 depicts the timeline of the experiment. First, participants read a tutorial describing the C^3Fire simulation and the goals of their mission, and they watched a demonstration of C^3Fire. After the tutorial, participants completed two familiarization scenarios. The first scenario lasted 15 minutes and was played individually. It allowed participants to familiarize themselves with the basic functionalities of C^3Fire. The second familiarization scenario, lasting 10 minutes, was performed with the other team members allowing them to learn to play C^3Fire as a team. Then, each team completed a 5-minute unsupervised planning session (which was recorded). Following this planning session, all teams completed four 10-minute test scenarios, each followed by a set of questionnaires (post-scenario questionnaires took 5-7 minutes completing). The experiment ended with a final set of questionnaires that addressed the overall experiment, which took participants between 20 and 30 minutes to complete. Teams could take a short break between scenarios if they felt the need, but there was no planned break.

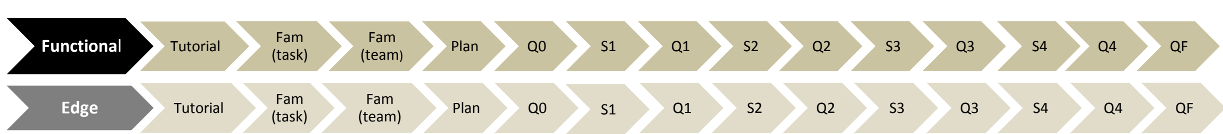

Figure 2. Experiment timeline.

Results

Given that C^3Fire logs yielded a considerable set of data, this paper focuses on a subset of the data pertaining to roles and behavioural indicators of role adoption in edge-like teams to compare with the roles allocated in functional teams. Specifically, we used the proportion of use for each type of unit (i.e., water, fuel, transportation, search, firefighter, and firebreaks) as a behavioural indicator to operationalize the various roles. For a given scenario, the proportion of use represents the number of times a type of unit was used by a participant over the total number of times this type of unit was used by the team. Role categories were based on the explicit role allocation in the functional condition (i.e., planning, operations, search and rescue, and resources management). Sending messages, which was a key action of the planning chief role, was considered as a unit even though there are no actual units attached to that role in C^3Fire.

The proportion of unit usage served as the basis for a two-step cluster analysis. The aim of cluster analysis is to separate data into meaningful groupings – or clusters – that exist in the dataset (Fraley & Raftery, 1998). The analysis was applied first on data from functional teams to determine whether team members clustered according to their assigned roles. Data from edge-like teams were similarly analyzed to determine the extent to which their use of each type of units by team members mapped on the roles allocated in the functional condition.

Functional Clusters

The two-step cluster analysis was run on functional teams first, using the Bayesian information criterion (BIC) to determine the optimal number of clusters to describe how each type of unit was used. The highest value on the silhouette coefficient (which measures cohesion and separation of clusters), partitioned the data in four clusters. As can be seen in Table 2, these four clusters represent the four roles explicitly allocated to team members in functional teams; that is, planning (cluster 1), operations (cluster 2), search and rescue (cluster 3), and resources management (cluster 4).

Table 2. Results of cluster analysis for the functional condition. Columns define the cluster categories. The values represent the proportion of use of each type of unit under each cluster.

Units	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Message	.98	.00	.00	.00
Firebreaks	.00	1.00	.00	.00
Water	.00	.00	.00	1.00
Fuel	.00	.00	.00	1.00
Firefighters	.00	1.00	.00	.00
Search	.00	.00	1.00	.00
Transportation	.00	.00	1.00	.00

Edge-like Clusters

To determine how the use of each type of units in edge-like teams compared to functional teams, the algorithm run on functional teams was rerun on data from edge-like teams. A total of five clusters emerged from this analysis to best describe the data, one more than in functional teams. As can be seen in Table 3, the content of each cluster is more mixed than for functional teams. When considering the two types of units most used in each cluster, two clusters correspond to explicit roles assigned in functional teams (cluster 2: search and rescue, and cluster 5: resources management). The other three clusters are characterized by combinations of the roles allocated in functional teams. That is, cluster 1is mostly a combination of operations and resources management, cluster 3, one of operations and search/resources management, and cluster 4 is a combination of the planning and search roles. Table 3 also shows that although there is some activity for each type of unit in every cluster, in a given cluster two or three types of units consistently stand out as being used more than the others.

Table 3. Results of cluster analysis for the edge-like condition. Columns define the cluster categories. The values represent the proportion of use of each type of unit under each cluster.

Units	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Message	.11	.02	.01	1.00	.05
Firebreaks	.02	.06	.90	.22	.01
Water	.37	.05	.10	.08	.75
Fuel	.05	.04	.22	.28	.78
Firefighters	.92	.03	.13	.01	.08
Search	.04	.36	.23	.56	.03
Transportation	.03	.93	.04	.17	.03

An examination of cluster membership for each team showed that aside from a few exceptions, teams fall under four of the five clusters for all four scenarios (i.e., a given team adopted four roles, not five[1]). Based on the proportion of unit usage, the four team members in edge-like teams adopted four different roles, one per team member.

To determine whether roles adopted in edge-like teams varied across scenarios, we measured the number of times cluster membership changed from one scenario to the other for each team

[1] As seen in Table 3, the proportions of use in the edge-like condition do not add up to 1. This is because the use of units across missions varies, and therefore not all clusters are represented in every mission (there can be data from one mission under one cluster but not another). This contrasts with the functional condition in which participants do not have flexibility in their roles, so every cluster is represented in each mission.

member in each team. That is, if a participant belonged to cluster 3 for the four experimental scenarios, it would indicate that he or she adopted a similar role throughout the experiment. If a participant belonged to cluster 3 for scenario 1 and cluster 5 for scenarios 2 to 4, it would suggest that he or she changed roles from scenario 1 to scenario 2. Results show that over the 288 possibilities for a role change (96 edge-like team members × 3 inter-scenario points), only 12 changes in cluster membership occurred, representing about only 4% of cases. In effect, roles adopted by edge-like teams were stable over time.

Impact of Scenario-Based Variables

Chi-square analyses were used to verify whether cluster membership is influenced by workload, time pressure or the order in which the mission scenarios were completed. These analyses were run separately for each condition of team structure. As expected, chi-square analyses showed functional teams cluster membership is not affected by time pressure, workload or the order of scenarios. As roles were explicitly allocated, team members did not have the opportunity to adjust their roles throughout mission scenarios in response to changes in the environment (all $\chi^2 < .001$, all *p*s > 1.00). More surprisingly, we observed a similar result with edge-like teams. That is, neither environmental changes (time pressure: $\chi^2 = .115$, $p > .95$; and workload: $\chi^2 = .103$, $p > .95$) nor the order of the scenarios ($\chi^2 = .514$, $p > .95$) had a significant impact on cluster membership. As with the lack of changes mentioned above, this suggests that team members kept the same roles they adopted during the first scenario throughout the various missions and that they did not significantly alter their roles in response to changes in the environment.

Discussion

The purpose of this paper was to investigate the extent to which edge-like teams adopt and organize roles differently from functional teams, and whether edge-like teams take advantage of the agility provided by the lack of structure to adapt role allocation over the course of various crisis management scenarios.

The proportion of use by team members of the different types of unit was used as a behavioural indicator of the various explicit roles in the simulation (e.g., operations, resources management, search and rescue). Using cluster analysis, we assessed the extent to which this indicator matched when comparing functional teams to edge-like teams. A behavioural indicator matching across the two conditions would create similar clustering in the two structures, indicating that edge-like teams adopted a structure similar to functional teams.

Overall, the study reveals that edge-like teams allocate roles somewhat differently than functional teams and that for a given team, role allocation remains relatively stable once established. More specifically, the cluster analysis yielded four main findings. First, the initial cluster analysis of functional teams separated participants into the four explicit roles allocated to team members in that condition. Second, when the same analysis was run on edge-like teams, only two clusters representing explicit functional roles were identified. The other three clusters that emerged described three different, combined, roles. Third, in the edge-like condition, team members did not significantly alter their roles in response to environmental changes (i.e., time pressure and workload), a flexibility that was not afforded to functional teams. Finally, role adoption in edge-like teams was stable over time. Participants in this condition retained the roles they adopted during the first scenario throughout the experiment.

Edge-like teams were given “carte blanche” as to how to go about assigning units, tasks and, therefore, roles amongst themselves. The cluster analysis reveals that edge-like teams emulated two of the four explicit roles of the functional condition, similar to the search and rescue chief, and the resources management chief, respectively. The other three roles identified by the analysis were edge-like specific and represented various combinations of units and tasks different from the assigned functional roles. Thus, despite a lack of instruction and predetermined structure to guide them in coordinating their actions, edge-like teams spontaneously adopted a set of distinct roles that only partly overlapped with the explicit functional roles. These results are consistent with those of Duncan and Jobidon (2008), who observed some evidence of self-synchronization with a large edge team performing an intelligence analysis task. In that study, the edge team had spontaneously adopted only a subset of the roles explicitly assigned in the hierarchical condition to which the edge team was compared. However, contrary to the findings of the present study, they did not find evidence of edge-specific roles.

As mentioned before, team structure can constrain information, task, and resources distribution, and therefore roles (e.g., Fong, 2006; Hollenbeck, 2000). In functional teams, tasks and resources (i.e., units) distribution was certainly constrained by the explicit roles assigned. Duncan and Jobidon (2008) posited that organizational differences between conditions (i.e., constraints stemming from team structure) can make some roles that exist in a structure superfluous in another. While we cannot say, based on our results, that a functional role was superfluous for edge-like teams, the clustering in the edge-like condition suggests that some functional roles were not preferred, as these teams adopted a more combined approach to managing their units and tasks.

The flexibility afforded by the edge-like structure could manifest itself in two ways; across teams and within teams. Indeed, each team could determine its own way to coordinate tasks and units, and it could also modify this role allocation throughout mission scenarios as they pleased. The findings show as a group, edge-like teams took advantage of the first aspect of this flexibility. Cluster membership indicates that the 24 teams are distributed quite evenly over the five clusters; most teams adopted four roles (i.e., were found in four of the five clusters), creating different combinations of roles. This finding echoes the results of Jobidon et al. (2013), who observed with edge teams that different teams behaved differently during the completion of the task. With regards to the second aspect of flexibility however, it appears that despite the flexibility to modify roles during and across mission scenarios, participants in the edge-like condition were quite stable in their adoption of roles. Indeed, aside from a few exceptions, the findings show that people kept their initially adopted role from the start of the experiment throughout all mission scenarios. Moreover, the fact that the order of scenarios and environmental changes (i.e., workload and time pressure) did not have a significant impact on cluster membership also supports the notion that role adoption in edge-like teams was stable over time and in response to changing demands in the environment. It should be noted that although these environmental changes, in particular workload, have been shown to impact performance in edge-like teams (see Jobidon et al., 2013), it is possible that they did not create conditions under which participants in the edge-like condition felt they could not accomplish the task with the roles they had adopted, and felt compelled to adapt them. Also, it is possible that with more experience with C^3Fire, participants could get even more comfortable in the task environment. This additional expertise could perhaps lead to teams displaying more flexibility in their roles from one mission to another.

One limitation of cluster analysis is that it is entirely determined by the variable selected to be analyzed (i.e., the data being clustered). This means that a different behavioural indicator may yield another, distinct, clustering from the one described in the present paper. However, in the context of C^3Fire and of this particular study, we believe that the proportion of use of the various types of units (including the task of sending situation reports) is an excellent and appropriate indicator of role adoption in edge-like teams. The clusters identified in the functional condition, which correspond perfectly to the explicit roles allocated to functional team members, support this proposition.

Conclusion

To further the understanding of flexible organizations and their potential benefits and limitations, we sought to examine how edge-like teams spontaneously adopt and organize roles when engaging in complex, collaborative activities in the context of crisis management situations. Our findings show that while there was some overlap in roles between functional and edge-like teams, the latter also adopted specific roles, distinct from the explicit roles allocated in functional teams. This provides evidence that in some contexts, edge-like teams take advantage of the flexibility afforded by the lack of structure to determine their own way of allocating roles and coordinating tasks. Once established, roles remained stable throughout all mission scenarios. This suggests that members of flexible teams do not necessarily feel the need to adjust their roles during the completion of the task just because they have the opportunity to do so, which could potentially create confusion and role ambiguity within the team. Flexibility, agility, and similar notions are increasingly encouraged in public safety and military organizations, in order to deal efficiently with the ill-defined and often high-tempo nature of the situations they face. More flexible organizations are one possible solution, and warrant further investigation to determine the conditions under which they can be a positive alternative to more traditional C2 structures.

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