Social Network Analysis, Team Cohesion and Meaningfulness of Tasks: A Comparison Between Two Different Command and Control Paradigms

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1 Executive Summary

What is this report about?

This report is about subjecting commonly held beliefs about the benefits of Network Enabled Capability (NEC) to direct empirical tests from a Sociotechnical Systems perspective. It is hypothesised that NEC should not just lead to widespread changes in the type and structure of communication but that this should be mirrored in a corresponding improvement in the experience of people working within it.

Background and reasoning behind the work:

There is good reason for wanting to endow command and control with open systems behaviour under the aegis of NEC. One reason is that experience within various civilian domains is encouraging; in particular, the use of Sociotechnical Systems theory has been bestowing NEC-like properties upon organisations for over fifty years and has an impressive track record of success. This provides the theoretical background necessary for exploring not just the technical effectiveness of NEC systems but also their success in terms of the experience of people working within them; an experience that is shown to be critical for eliciting the type of self-synchronisation hoped for.

What was undertaken in the research?

The Brunel University NEC test-bed enabled a traditional hierarchical command and control organisation to be pitted against a network centric alternative on a common task, performed thirty times, by two teams. Social Network Analysis provided a means to analyse the content and structure of communications which was complemented by a self-report cohesion questionnaire.

What was discovered?

The results of a Social Network Analysis show that the NEC condition facilitated more communications and informationally richer ones too. There was also structural evidence to suggest the presence of elevated levels of distributed leadership and autonomy. The main finding was that this translated into a subjective experience of the same, as measured by a simple self-report team cohesion scale.

Military relevance of the work:

The current study provides an interesting advance on existing methods and an empirical basis to support one of the central assumptions driving forward the implementation of NEC.

2 Introduction

2.1 Classic Command and Control

Command and control (C2) is the management infrastructure for any large, complex, dynamic resource system (Harris & White, 1987). Traditional forms of C2, and by this we refer to the stereotypical notion of a hierarchically disposed chain of command comprised of layered echelons, is predicated on rationalistic principles (e.g. Weber, 1930). As such, so-called 'classic C2' can be seen as exhibiting the recognisable hallmarks of the following four rationalistic principles. It is:

- Efficient (as in "…the most efficient structure for handling large numbers of tasks"; Ritzer, 1993, p.20),
- Predictable (in that recipients of the 'services' that C2 dispenses "know with a high degree of confidence what they will receive and when they will receive it"; Ritzer, 1993, p. 21),
- Quantifiable (in that the "performance of the incumbents of positions within [classic C2] is reduced to a series of quantifiable tasks"; Ritzer, 1993, p. 21),
- And finally, controllable (because in one sense classic C2 can be seen as a form of nonhuman technology, its "nearly automatic functioning may be seen as an effort to replace human judgement with the dictates of rules, regulations and structures"; Ritzer, 1993, p. 21).

The manifestation of these organisational characteristics is in turn predicated on a further set of beliefs, often implied. The first of these is a belief in the appealing cause and effect logic of control theory, whereby "Changes in inputs equate to proportional changes in outputs" (Alberts & Hayes, 2006 p. 84). This belief underpins the dominant strategy for classic C2's attempts to cope with complexity, which is: "…the problem of military decision-making is decomposed into specialized functional roles…a system of echelons is employed to ensure both appropriate span of control [middle managers] as well as what happens to and within the elements of the force, and to act as control agents to ensure that guidance is understood and followed" (Alberts & Hayes, 2006, p. 84). Furthermore, "hierarchies involve very few horizontal linkages" (p. 100) and all role incumbents should have "all the assets needed to complete a task or mission" such that "no other organization will interfere with their efforts" (p. 89). In its stereotypical form traditional C2 relies on deconfliction, decomposition, vertical linkage and a fundamental, overarching belief in linearity. The more this belief is realised in practice, the more successful the infrastructure.

Despite the appealing rationalistic, control theory logic of cause and effect, in which outputs should be proportionate to inputs, it is nonetheless fair to say that current day command and control can still exhibit paradoxical behaviour. To paraphrase Ritzer (1993, p. 22), classic C2, whilst often highly efficient for those at or near the top of the hierarchy, can sometimes be drastically inefficient for those lower down. Classic C2 can also degenerate into unpredictability as the asymmetric nature of modern military contexts leads to outcomes that are grossly disproportionate to the input that caused them; as such, the recipients of the 'services' that C2 dispenses often do not get what they expect. Finally, the emphasis on quantification can also lead to a large quantity of tasks being carried out (e.g. missions being flown and/or bombs being dropped), yet with little meaningful 'effect' (e.g. targets destroyed or enemies defeated; Storr, 2005). Paradoxically, this means that "*what were designed to be highly Rational operations often end up growing quite irrational*" (Ritzer, 1993, p.22).

2.2 Network Enabled Capability

Network Enabled Capability (NEC) is the conceptual response to these challenges and a new type of command and control predicated on something different (NATO, 2006, p. 1). NEC's central tenets are as follows:

1. "A robustly networked force (enterprise) enables the widespread sharing of information.

2. Widespread information sharing and collaboration in the information domain improves the quality of awareness, shared awareness, and collaboration (C2 operations and processes).

3. This, in turn, enables self-synchronisation.

4. This results in a dramatic improvement in operational effectiveness and agility" (NATO 2006, p.1).

To varying extents, these tenets are conjectural, forming hypotheses as to expected outcomes, in broad terms hypotheses that the current study speaks towards. What is interesting is that the implicit theory underlying them is not control theory or determinism, but systems theory and probabilistic behaviour. Indeed, the term 'Network' (of Network Enabled Capability) is often assumed to refer to the networked technology underpinning tenet #1 above yet it is more correct to say that it derives from systems theory and describes a particular type of system; an open-system. Open systems have boundaries with other systems and there exists some form of informational exchange between them. According to the pioneer systems theorist von Bertalanffy, "An open system may attain (certain conditions presupposed) a time-independent state where the system remains constant as a whole…though there is a constant flow of the component materials. This is called a steady state" (1950, p. 23). In NEC parlance the same phenomena is called 'self-synchronisation'.

An organisation endowed with this open systems behaviour is ascribed an organic metaphor. "When we refer to an organisation as being 'an organism', we mean it behaves in similar ways to our own biological mechanisms. When the environment around and within us changes, our bodies adapt" (Arnold, Cooper & Robertson, 1995, p. 14). Framed in the language of NEC, self-synchronizing forces "work together to adapt to a changing environment, […] to develop a shared view of how best to employ force and effect to defeat the enemy. This vision removes traditional command hierarchies and empowers individual units to interpret the broad command intent and evolve a flexible execution strategy with their peers" (Ferbrache, 2003, p. 104). The evolution of flexible execution strategies relies in turn on feedback. An appropriate analogy might be between an organisation like NEC that can use feedback to 'learn' on-the-fly, compared to one like classic C2 that cannot use feedback in the same way and is 'programmed'.

2.3 Sociotechnical Systems Theory

Sociotechnical systems theory serves as the background and context to this work. It derives from long standing observation of rational organisations that behave irrationally. It is a set of theories and approaches that speak towards joint optimisation of human (socio) and technical aspects of a system in which the needs of humans at work are seen to be isomorphic with organisational (systemic) success. Indeed, in an increasingly complex, high tempo environment, optimisation of the human aspect of systems is seen to be a key determinant of success.

As well as being a 'theory' and an object of academic enquiry, sociotechnical systems theory can also be regarded as a business process re-engineering 'approach'. As an approach, it has been endowing numerous civilian organisations with open-systems properties for several decades. This takes various forms but usually focuses on what militarily would be called small agile teams, peer-to-peer working, responsibility and ownership of a task resting with that team, combined with effects based planning and operations. In other words, sociotechnical systems theory overlaps almost entirely with the aims and aspirations of NEC. The sociotechnical approach, however, has something that NEC currently lacks: a fifty year track record (Cummings, Molloy and Glen, 1977; Pasmore et al., 1982; Beekun, 1989).

Despite the lack of overt cross-referencing the degree of overlap between the parallel concepts of NEC and sociotechnical systems is remarkable. For example, what NEC refers to as Effects Based Operations (the 'broad command intent' referred to above), sociotechnical systems theory refers to as 'minimal critical specification', meaning simply that "While it may be necessary to be quite precise about what has to be done, it is rarely necessary to be precise about how it is done" (Cherns, 1976, p. 786). The world of Ergonomics might further recognise this concept in Annet et al's (1971) first principle of human performance: that a task can be defined in terms of its objectives or end products. In whichever case, the extra degrees of freedom that this bestows upon those tasked with their achievement goes hand in hand with the sociotechnical concept of semi-autonomous work groups. The key feature of this concept is a shift in the unit of analysis from the organisation as a whole to that of the group. In particular, that internal supervision and leadership resides at the level of the 'group' (e.g. Trist & Bamforth, 1951). Peer-to-peer interaction is the term coined to explain this same characteristic within NEC.

When peer-to-peer interaction is combined with effects based operations, it is internal supervision that is assumed to create the conditions for the evolution of flexible execution strategies. Herein lies the final key overlapping concept: adaptability (sociotechnical systems) or agility (NEC). The issue here can be described thus: "A very large variety of unfavourable and changing environmental conditions is encountered […], many of which are impossible to predict. Others, though predictable, are impossible to alter." (Trist & Bamforth, 1951, p.20). In other words, it is increasingly difficulty to maintain the environment in a passive and stable state through the imposition of control-theoretic logic. Even when this logic is imposed, the danger (and prime cause of irrational system behaviour) is that problems become magnified through a much larger, more tightly coupled social space. For example, there is a much higher degree of task interdependence in a hierarchically disposed command and control entity like classic C2 than there is in one based around a looser, effects based arrangement of peer-to-peer groups, as found in NEC.

It can be seen that not only do key concepts in sociotechnical systems theory and the emerging arena of NEC overlap, they are virtually isomorphic. But despite these similarities, the value bases underlying each field are somewhat different; generally speaking the role of humans in NEC tends to be downplayed in favour of the supporting networked technology (what is all too commonly thought of as the 'Network' part of 'Enabled Capability'). This in turn creates a danger that NEC is viewed merely in terms of its objective characteristics, for example, to use the language of the NATO SAS-050 conceptual model of command and control (NATO, 2006), NEC can be defined structurally as an organisation embodying peer-to-peer decision rights, fully distributed patterns of interaction and broad dissemination of information. Yet having set these organisational parameters it is still the case that effective human performance remains far from an automatic occurrence (Salas, Bowers, Cannon-Bowers, 1995).

There is considerable value in testing these assumptions about NEC and asking how the structural determinates of NEC map onto the experiences of the individuals working within it. Lest there be any doubt as to the importance of this, bear in mind that self-synchronisation relies on the adaptability of humans to their immediate context, it relies on the human ability to be able to meaningfully interpret broad command intent, and all of this seems to rely, critically, on the cohesiveness of the small group that has suddenly become the focus of analysis. The question, then, is whether the objective, structural determinates of NEC relate in turn to the important human attributes that are both a cause and a consequence of self-synchronisation?

2.4 Meaningfulness of Tasks

Sociotechnical systems theory is built on an overtly human centred value base and has the language and metaphors required to examine 'meaningfulness of tasks' more closely. Under conditions of classic C2, the sociotechnical systems literature might highlight the fact that the work exhibits the properties of being "broken down into a standard series of component operations that follow each other in rigid succession" (Trist & Bamforth, 1951, p.11). Live observations of military planning and operations are not completely at odds with this view, in some broad sense at least. Furthermore, in terms of scale, the work is almost always undertaken as part of a much larger macro-level activity, which reduces the proximity and immediacy of some communications, thus frequently transcending "the limits of simple spatio-temporal structure. By this is meant conditions under which those concerned can complete a job in one place at one time, i.e., the situation of the face-to-face, or singular group" (Trist & Bamforth, 1951, p. 14).

According to the sociotechnical literature, meaningfulness of tasks is achieved by placing responsibility for a complete task on the conceptual shoulders "of a single, small, face-to-face group which experiences the entire cycle of operations within the compass of its membership." So "for each participant the task has total significance and dynamic closure" (Trist & Bamforth, 1951, p. 6). Hackman and Oldman's (1980) core job characteristics enable these concepts to be expressed in more explicit terms, with meaningfulness of tasks arising from the following five attributes:

1. Skill variety (or the deployment of a multiplicity of skills).
2. Task Identity (or 'whole tasks').
3. Task Significance (or total significance).
4. Autonomy (and leadership residing at the level of the group).
5. Feedback (or knowledge of results; Annett and Kay, 1957).

Having defined meaningfulness of tasks with reference to the sociotechnical literature and mapped it across to five core job characteristics, attention now turns towards its measurement in some military relevant sense. The concept of 'cohesion' presents itself as a good candidate.

Cohesion is a multidimensional facet of team working generally held to be comprised of a liking for and/or commitment to group membership, task performance and the team's prestige or pride (e.g. Festinger, 1950; Siebold, 2000). The concept is far from fully resolved theoretically (e.g. Siebold, 2000) but this need not concern us excessively for current purposes; the parallel concept of meaningfulness of tasks lends cohesion a degree of construct validity.

Cohesion has been shown to facilitate strong interpersonal bonds, the desire to remain in a team, increased sharing of information and a higher level of enjoyment combined with lower levels of stress (e.g. Bartone, 2002; Siebold, 2000). All of this can be related back to the NATO SAS-050 model of command and control and the structural determinates of NEC it specifies. It seems reasonable to suspect, therefore, that peer-to-peer decision rights could (or should) create the conditions for stronger interpersonal bonds. Broad dissemination of information seems to map on to the idea of increased information sharing and feedback, and distributed patterns of interaction map well onto internal leadership and supervision, which in turn maps well onto ideas about autonomy. Higher levels of enjoyment and/or satisfaction, if Hackman and Oldman's (1980) core job characteristics are to be used, should be derived from these factors as they relate to task significance, coherence, the application of a multiplicity of skills, all of which are undertaken during a complete task cycle.

2.5 Hypotheses

Cohesion, as a high-level human-centred concept, maps onto meaningfulness of tasks and it has been argued that it is just as important for the 'dramatic improvements in operational effectiveness and agility' that NEC aspires to as the structural determinates of the organisation alone. Although the implication is that these objective determinates of NEC create the conditions for meaningfulness of tasks, an opportunity arises in the present study to put this supposition to a direct empirical test. Thus the experimental hypotheses are as follows:

Hypothesis 1: Quantity and structure of communications. It is expected that NEC will change the quantity, type and structure of communications when compared to a classic C2 control condition.

Hypothesis 2: Meaningfulness of tasks. Changes in the quantity, type and structure of communications will be accompanied by a corresponding change in the extent of task meaningfulness as measured by cohesion. The NEC condition should demonstrate higher levels of cohesion than the C2 condition.

The next section describes the novel way in which these hypotheses are tackled experimentally.

3 Method

3.1 Design

The study is aimed at assessing the effects of NEC's structural determinates (using Social Network Analysis) on the human centred concept of meaningfulness of tasks (using the concept of cohesion). The study adopts a micro-world paradigm which aims to preserve the critical task variables encountered in live settings. A large part of this derives from the simplified 'Military Operations in Urban Terrain' (MOUT) game called 'Safe houses' that formed the experimental scenario.

The game creates a dual task paradigm. The first task involves a commander managing two live fire teams as they negotiate an urban environment en-route to a 'safe house'. The second task involves the commander managing the activities of ten further simulated fire teams within a much wider Area of Operations. The two tasks interact with the job of managing time and resource conflicts falling to the commander such that success in one task does not necessarily connote success overall.

The safe houses game occurs under the independent, between subjects variable of command and control 'type', which has two levels: NEC and C2. The study is longitudinal in nature. Two teams (NEC and C2) separately undertook a total of thirty iterations through the same dynamic task paradigm and their adaptation to the structural determinates of the command and control organisation(s) was measured.

In part one of the results, thirty separate Social Network Analyses were undertaken, with the network metrics (the dependent variables) subject to a simple form of regression-based time series analysis in order to reveal the underlying 'adaptive model' in the data. In addition, an analysis of communications quantity and content (also dependent variables) was undertaken using a pre-defined communications taxonomy.

In part two of the results the dependent variable was the subjective experience of the role incumbents, which was measured over seven intervals using a modified self-report cohesion questionnaire.

Participant matching and task randomisation were employed to control for individual differences and task artefacts respectively.

3.2 Participants

There are five principle roles within the C2 and NEC conditions (ten in total). In each condition, three roles were occupied by experimental participants (all aged 21) who were recruited from the wider University community. Each team of three participants stayed together within their respective condition (C2 or NEC) for the duration of the study. The remaining two roles were filled by the experimenters in both conditions. The roles were as follows:

NEC System Operator (Experimenter):

In general, the NEC System Operator dealt with the experimental aspects of the Commander's Primary Task (managing the fire teams) as well as the NEC system itself. Thus the first experimenter effectively 'drives' the NEC command wall system, receives requests to add/append data to the live maps from the commander and helps them to use the system themselves. The system operator also supplies scenario injects according to pre-set rules dependent on experimental condition and the state of game play. In the NEC condition, the experimenter also provides situational updates to all team members (ensuring that 'everyone' knows 'everything').

Commander (External Participant):

The incumbent of this role was in charge of both fire teams (within the Primary Task), providing guidance and strategy as required, they were also responsible for the larger strategic Secondary Task.

Fire team Alpha (External Participant):

This participant was located within the live battlespace and communicated to the commander, and depending on experimental condition, the other fire team as well, by using an XDA mobile device (a branded 'next generation' Personal Digital Assistant) and MSN Messenger™. The XDA device also enabled the fire team to be live tracked and represented on the commander's command wall representation of the battlespace.

Fire team Bravo (External Participant):

This participant had the same role and capabilities as Fire team Alpha.

Enemy (Experimenter):

This individual, like the NEC system operator, was another member of the experimental team located away from the battlespace and from the commander. They were in charge of playing the enemy commander (to the best of their abilities) in the Secondary Task, thus they controlled enemy actions in a 'Wizard of Oz' fashion.

3.3 Materials

3.3.1 Command and Control Microworld Environment:

Figure 1 presents a visual representation of the command and control microworld within which the Safe houses game was played.

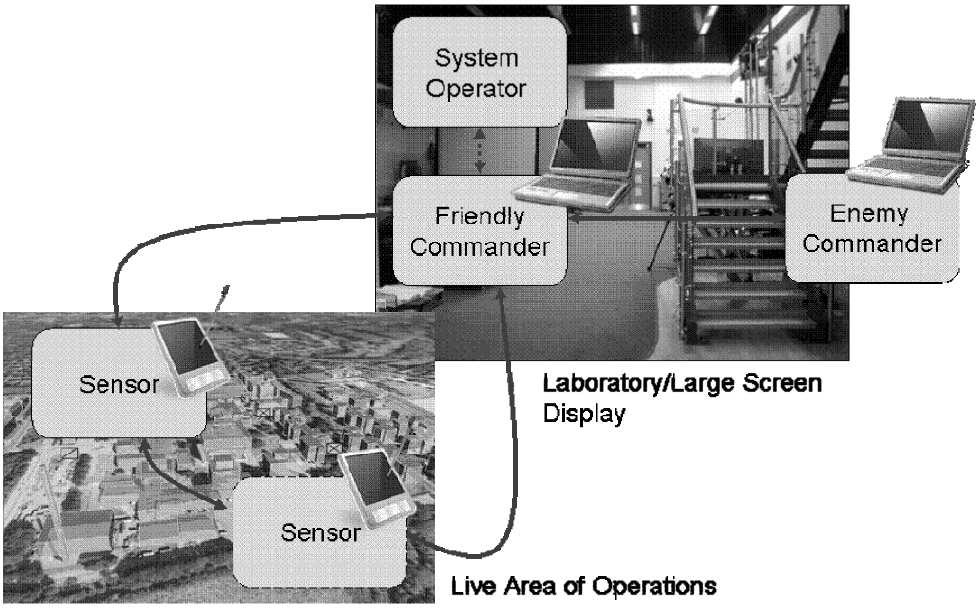

Figure 1 – Command and control microworld

The system operator and commander were co-located indoors. Both sat with a clear view of a large digital command wall containing a Google Earth™ representation of the virtual battlespace, with the position of the fire teams represented by an icon derived from Global Positioning System (GPS) data (thus positional tracking of the fire teams was live). This visualisation window was supplemented by a planning window that contained a map based representation of the same environment with a grid square coordinate system. The planning window allowed the system operator and commander to add, delete and move objects as required by the primary and secondary tasks, which were then instantaneously represented on the main visualisation window. The planning window was populated by the experimenter (before the condition commenced) with all the required safe houses, enemy icons and other data entered according to a preset template randomly selected for that trial. The commander and system operator had separate work stations and their own computer, and communicated purely through text based means (using MSN Messenger™).

Both fire teams (Alpha and Bravo) were located outdoors within a defined ‘battlespace’. The fire teams carried an XDA mobile phone device, permitting them to be live tracked using GPS. The XDA device also allowed each fire team to communicate with the commander and, depending on experimental condition, the other fire team (via MSN Messenger™). Fire teams could add icons into their own version of the digital map, which would then simultaneously appear on the main visualisation window in the control centre. The digital map shown on the fire teams’ XDA screens was also used for navigation purposes.

3.3.2 Command and Command Paradigms:

The NATO SAS-050 model of command and control (NATO, 2006) was used to design command architectures that exhibited appropriate NEC and C2 structural characteristics as shown in Table 1.

Table 1 – NATO SAS-050 Model of Command and Control was used to design NEC and C2 command organisations with the appropriate characteristics

	NEC	C2
DISTRIBUTION OF INFORMATION	BROAD: fire teams are provided with regular situation updates from the system operator (in addition to being able to interact directly with their counterparts. ‘Everyone’ knows ‘everything’.	TIGHT: the commander is the only individual with an overall view of the situation. The fire teams had a local view of their immediate location but in all other respects work in isolation. ‘Everyone does not know everything’.
PATTERNS OF INTERACTION	DISTRIBUTED: all team member roles can speak to each other independently (there is no communications hierarchy).	HIERARCHIAL: the fire teams could speak to the commander but not directly to each other.
ALLOCATION OF DECISION RIGHTS	PEER TO PEER: collaborative working encouraged and facilitated by effects based instructions and communications infrastructure.	UNITARY: autonomy, authority and discretion rested with the commander.

3.3.3 “Safe houses” Game (Primary Task):

The use of a micro-world strategy brings to the study a certain degree of simplification and abstraction. As a result, information overload, resource attrition by the dissemination of non-relevant information, and deception, though potentially real components of live NEC are not overt features of the current study. In experimental terms the salience of information (all information in the environment is salient) and deception (not present) are held constant to allow the effects of communications structure and cohesion to be observed. Having specified these initial conditions it is entirely permissible for such aspects to emerge. Indeed, the social network is able to detect information bottlenecks and perhaps resource attrition, even the effects of deception. Whilst possible, they are not the focus of the current study.

The goal of the primary task (that of the live fire team in the outdoor battlespace) is to: “Execute a concentrated and simultaneous operation to disrupt a named suspect by searching their house in order to gather evidence to disrupt and dislocate enemy force elements within that Area of Operations” (MoD, 2005).

In a practical sense this involves the fire team choosing and negotiating a route through the urban battlespace in order to correctly locate and effect the safe house, dealing with Target Areas of Interest (TAIs) en-route, with each team having to collaborate by providing cover for each other. Both fire teams start from the same location. The location of the safe house, the final destination, is randomised for each trial but with distance from start point controlled. The Area of Operations (AO) for the primary task is scattered with numerous Target Areas of Interest (TAIs) so that an equal number of TAIs will be encountered 'en-route' (and regardless of route chosen).

Firstly, each of these 'en-route' TAIs has to be correctly located by one of the fire teams. Correct location of a TAI is judged to have occurred when the fire team takes up position at the same grid coordinates as the TAI. Missing out a TAI by failure to locate it will result in the offending fire team being removed from the mission and having to return to the start point for the remainder of the trial.

Secondly, assuming the en-route TAI has been correctly located, the fire team then has to effect it in order to make it safe for the other fire team to continue on the designated route. Although the location of the TAI is known by the fire team and commander a-priori, what is not known is what form the TAI actually takes and the most appropriate way to effect it. This can only be judged by the fire team who are on the ground and are able to make that assessment based on a number of simple local characteristics. These are as follows:

- If the TAI is located on a building over three stories high then a 'yellow effect' will neutralise it (signified by the relevant fire team using their XDA to place a yellow icon on the appropriate grid coordinate).

- If the TAI is located on a building less than three stories high, then a 'blue effect' will neutralise it (signified by a blue icon being placed).

- If the TAI is located in a busy thoroughfare with retail outlets then a 'pink effect' will neutralise it (signified by a pink icon).

After confirmation that this information has been received, the relevant fire team will hold in this position, providing cover for the other fire team as they make their way to the next TAI. This 'leap-frogging' effect continues until, finally, the safe house itself is located and effected in the same way. It should be pointed out that in the NEC condition this leap-frogging is facilitated by the fire teams being able to communicate directly with each other via their XDAs; in the C2 condition, however, communication (and instructions) have to pass through and/or come from the commander. In order to further encourage the need for communication and interaction there is also a degree of in-built ambiguity in the positional data. This means that part of the adaptive process of the entire team is to figure out 'work arounds' and modes of operation that enable these ambiguities to be resolved in whatever way is found to be most efficient.

The need for good time and accuracy performance is embedded in the game by two simple game-play expedients. As mentioned before, if the wrong location is chosen or the TAI is ignored then the fire team allocated to it fails the mission and has to sit out the remainder of the trial. If the right location but wrong effect is applied then the fire team's 'attrition score' is decremented. This score acts rather like a 'life score' starting at five and meaning 'full strength', through to zero, meaning 'neutralised and unable to continue the task'. The attrition score is not just affected by accuracy but also speed and time.

Five time activated attrition injects occur throughout the 15 minutes allotted to the trial; these cause both fire teams' attrition scores to be decremented. As a result, the longer the fire team takes, the longer they expose themselves to the deleterious effect of the experimental injects. This combines with accuracy: the less accurate they are the lower the score.

What appears to be a relatively complex set of rules becomes considerably simplified as far as the experimental participants are concerned. The system operator (who is a member of the experimental team) undertakes all game play management tasks such as maintaining the formal record of 'location accuracy', 'effect concordance' (whether the right effect has been applied), the attrition score, enactment of the time based attrition injects, and communicates all of this to the commander as required.

3.3.4 Secondary Task (Commander):

The commander's secondary task is based on the following mission: "Execute a concentrated and simultaneous operation to disrupt named suspects by searching their houses in order to gather evidence to disrupt and dislocate the enemy force within West London"

Whilst the first task concerns the activities of a live fire team in a local environment, the secondary task of the commander concerns the activities of simulated fire teams within a much larger Area of Operations (AO; e.g. the boundaries are six miles in either direction from the AO of the first task). This larger strategic mission relies on the commander playing a competitive game against a simulated 'enemy', played by the experimenter acting in a wizard of oz fashion. Thus 'live' (small AO) and 'simulated' (large AO) elements are played simultaneously on the same NEC system. So whilst the live fire team progress towards their primary target within their smaller AO, wider enemy activity is taking place all around which, if permitted to continue, will eventually impinge on the primary task. Such impingement, under certain specified conditions, will mean that the primary task fails regardless of the efficacy of the fire teams. The onus is thus on the commander to manage both tasks effectively.

In the commander's wider Area of Operations there are 15 enemy elements/icons dispersed randomly around the environment. These icons are placed according to a random script for that trial by the experimenter acting in the 'enemy' role. Enemy icons, due to the asymmetry of most MOUT-type situations, are free to move across the battlespace at will (no area is restricted to them). The commander has 25 friendly force icons/elements all massed in a defined 'green zone'; this is their starting position. Although more numerous, the friendly icons are not permitted to enter pre-defined 'sensitive areas'. Apart from these constraints, the game plays like a virtual game of 'draughts' in which the grid square system of the map serves as a form of draughts board. Only one icon can be moved, one square at a time (in any direction) in enemy reaction, friendly counter action, enemy counter re-action, and so on in sequence. If the friendly icon enters a grid square occupied by an enemy icon then the friendly icon wins. If the enemy icon enters a grid square occupied by a friendly icon, the enemy wins. The experimenter playing the role of enemy updates the icons/map accordingly (and keeps a record of the game score). The enemy's objectives are to reach several other enemy safe houses dotted around the AO (one of which is the primary target for the live fire team). Every enemy icon that enters the grid square occupied by a safe house is safe and no longer available to be 'captured' or 'neutralised' and thus no longer able to contribute to an 'enemy captured/neutralised' score. As a result, the onus on the commander is to capture/neutralise the enemies before they reach a safe house, and preferably, neutralise the safe house before enemies start to reach it, hence the phrase 'disrupt' and 'dislocate'. In numerical terms, the goal is to capture as many enemy icons as possible for the least cost in terms of friendly icons.

3.3.5 Cohesion Questionnaire:

A modified version of the Combat Platoon Cohesion Questionnaire (Siebold & Kelly, 1988) was deployed. The modifications took the form of shortening the original 88 item questionnaire down to just 15 items. The rational for this was as follows. Firstly, the longitudinal nature of the study and the multiple measures being extracted placed severe time constraints on this activity, meaning that there was not sufficient time to administer the full questionnaire. Secondly, items were chosen on the basis of their mapping to the 'task meaningfulness' concepts that were of interest in the current study, and thirdly, minor contextual revisions were undertaken (i.e. removal of references to a specific armed force). As a result of these steps it is fair to say that what remains is a much simplified assessment of cohesion, yet one that should still be capable of detecting changes in the subjective experience of people operating under the conditions specified by the independent variable (NEC or C2). The 15 items required a response along a 7 point Likert scale (a score of 1 equating to the maximum score on a particular cohesion question, 7 the minimum). The question items, and the corresponding mapping to Hackman and Oldman's (1980) core job characteristics, are shown below in Table 2. Note that this mapping is approximate and to some extent the existing construct validity of the question items can also be relied upon.

Table 2 – Question items drawn from the Platoon Cohesion Questionnaire (Siebold & Kelly, 1988) mapped onto Hackman and Oldman's (1980) core job characteristics to create a much simplified assessment method

Question Item	Core Job Characteristic				
	Skill	Task Identity	Task Significance	Autonomy	Feedback
These items rated from 'not at all important' to 'extremely important'					
Loyalty to the team		■			
Taking responsibility for their actions and decisions				■	
Accomplishing all assigned tasks to the best of their ability			■		
Commitment to working as members of a team		■			
Dedication to learning their job and doing it well	■				
Personal drive to succeed in the tasks			■		
Taking responsibility to ensure the job gets done				■	
The team can trust one another		■			
Feel close to other team members		■			
Question Item	Core Job Characteristic				
	Skill	Task Identity	Task Significance	Autonomy	Feedback
These items rated from 'very much/well/always etc' to 'very little/poorly/not at all etc'					
How well do the members in your team work together?		■			
To what extent do team members help each other to get the job done?				■	
To what extent do team members encourage each other to succeed?			■		
Do the members of your team work hard to get things done?				■	
The chain of command works well?					■
Everyone is well informed about what is going on?					■

3.4 Procedure

3.4.1 Training Phase (Day 1):

The aims and objectives of the study were introduced in broad terms, along with health and safety preliminaries and informed consent. Detailed instructions on the task were then provided to all participants, supplemented with demonstrations and hands-on examples. The experimenter then used the pre-populated command wall to begin the first full trial, which was identical in all respects to the experimental trials, but in this case served merely as a practice. However, both teams were subsequently measured as an internal check on concordance and no one team emerged as innately better than the other.

The fire teams were equipped with the XDA and briefed by the commander, with the help of the study team, as to the mission objectives. The study was timed from the moment the fire teams left the designated start point. The commander was seated in front of their own laptop computer and the command wall. With all participants ready the practice trial commenced with help, facilitation and intervention from the experimental team as required. The System Operator managed the experimental tasks associated with the Primary Task (attrition scores, communications updates – where required and permitted - and timing). The Enemy commander played the friendly commander concurrently according to the rules of the game. After a maximum of 15 minutes (or sooner if the Primary Task was completed) the trial was halted, and the MSN transcripts were saved/archived along with those of the command wall's system logs

3.4.2 Experimental Phase (Day 1 – 7):

The training phase took place on the morning of the first day. The experiment got under way proper on the afternoon for a total of seven days evenly spread over the course of two weeks. Between three and five trials were undertaken per day, alternating between experimental conditions. Issues and questions were dealt with before the trial started and during it if required.

4 Results Part 1: Quantity and Structure of Communications

Hypothesis 1 states that NEC will change the quantity, type and structure of communications when compared to a classic C2 control condition. The following sections interrogate the results in order to support or refute this position.

4.1 Quantity of Communications

NEC Participants took part in a simulated MOUT mission over thirty successive iterations. All communications undertaken in the study were done so using a proprietary messenger software system enabling the total number of communications events that occurred within each trial to be counted.

In the case of both NEC and C2 conditions a linear relationship between the number of communications and the number of trials is apparent from the scatter plot shown in Figure 2, at least to the extent that values can be seen to generally decrease with time. A relatively strong negative association between the number of communication exchanges and trial interval is in evidence: $r = -0.43$ (NEC) and -0.72 (C2), both of which are statistically significant beyond the 1% level. This reflects the general trend towards fewer communications events as the number of trials increases, with this trend being more pronounced for the C2 condition. According to the regression ANOVA there is good statistical support for the linearity observed in the data: $F(1,28)=6.18/29.56$; $p<0.05$ (NEC) and $p<0.0005$ (C2).

The regression models fitted to this data differ in respect to the amount of variance they explain. The variance explained in the NEC condition is of the order of 15% (Adjusted $R^2 = 0.15$) whereas the model constructed for the C2 condition explains substantially more at 50% (Adjusted $R^2 = 0.50$). In other words, the number of communications in the C2 condition behaves as though it is attracted more linearly towards lower values than the NEC condition. Indeed, Figure 2 shows that the intercepts (b_0) cross. The C2 condition starts off with more comms events than the NEC condition (40.2 comms events versus 36.08) but the higher regression coefficient ($b_1 = 0.51$) leads this situation to invert with time. In rationalistic terms C2 could certainly be viewed as 'efficient' but fewer communications may not be better. Note that both regression models (C2 and NEC) are demonstrative of a large effect size and are both statistically significant beyond the 5% level.

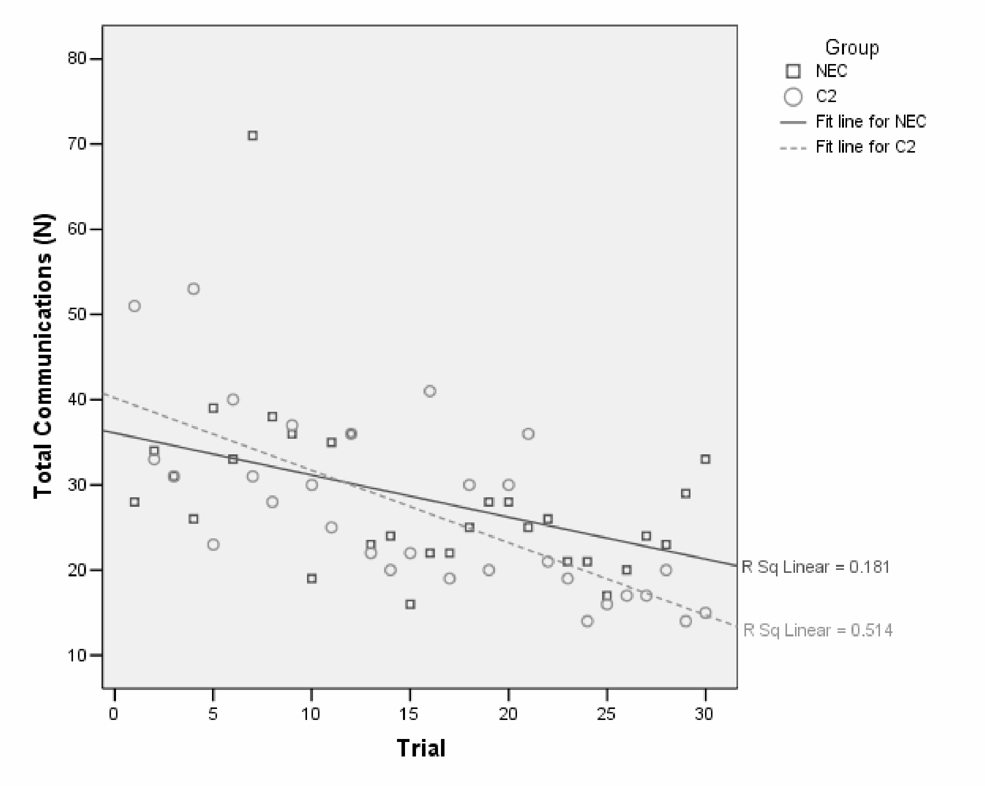

Figure 2 - Scatter plot showing the regression lines for both NEC and C2 conditions in relation to total communications

4.2 Structure of Communications

In the current study the structure of communications (as in who can speak to whom) is less constrained in the NEC condition than it is in the C2 condition. In the NEC condition everyone can speak to anyone (if they want to) whereas in the C2 condition the structure of communications is fixed and all communications have to pass through the commander. It is clear from the above that the C2 condition did not adapt to its constricted comms architecture by enacting ‘more’ communications; in fact, the opposite was true. What else can be discerned?

Social Network Analysis (SNA) lends itself well to examining the structural determinates of communications. A social network can be plotted by examining ‘who’ is communicating to ‘whom’. The presence of a communication establishes a link between any actors that are communicating with each other, creating its own structure in the form of a social network. The network can then be examined mathematically to identify key characteristics such as sociometric status (who, based on their degree of interconnection, can be regarded as a key agent) and density (how densely interconnected the network as a whole is). In the present case, density and sociometric status did not behave in a way that made the linear regression method of time series analysis tenable. In terms of both these measures the regression diagnostics showed only weak (and non-significant; p=ns) associations between them and trial interval. Likewise, the regression ANOVAs failed to detect a meaningful and/or significant effect in terms of the data behaving linearly. This form of modelling is therefore substituted for a more conventional cross-sectional analysis.

The simplicity and constraints imposed on both the NEC and C2 social networks are clearly evident in the behaviour of the density metric. In both cases (albeit during different trial intervals) the density figure only deviated from a fixed point on three occasions. This behaviour makes non-parametric tests appropriate. The results show that the mean density figure in the NEC condition (M = 0.97, SD = 0.1) was somewhat higher than the C2 condition (M = 0.61, SD = 0.19). A Mann-Whitney U test goes on to suggest that the NEC social network is significantly more dense (U = 40.5; exact $p < 0.0001$) than the C2 network, meaning that the opportunity for peer-to-peer collaboration was in fact taken. The approximate effect size of this finding is $r_{bis} = 0.25$, a relatively small effect yet one consistent with the small size and simple characteristics of the networks under analysis. The findings for sociometric status are presented in Table 3.

Table 3 – Results of analysing sociometric status in relation to NEC and C2 conditions

Agent	Organisation	Mean Sociometric Status	Standard Deviation	U Statistic	Exact p	Approx Effect Size (r_{bis})
Commander	NEC	7.88	3.27	52.5	< 0.0001	0.26
	C2	20.95	8.99			
Alpha	NEC	11.92	2.73	417	= 0.32	0.04
	C2	12.02	5.39			
Bravo	NEC	12.13	3.29	222.5	< 0.001	0.22
	C2	8.93	4.12			

The pattern of results shown above in Table 3 presents a coherent picture. As expected, in the C2 condition the commander has significantly elevated status compared to the NEC condition. By comparison, the presence of peer-to-peer working within the NEC condition significantly elevates the status of the agent called Bravo. Taken together, the findings for sociometric status and density show that small, yet significant, meaningful and robust changes in network structure did occur within the current study. Within the NEC condition the opportunity for peer-to-peer interaction was taken, which, in combination with elevated levels of communication traffic, led to higher network density and a more even spread of sociometric status across agents. This, then, is evidence of internal leadership and autonomy, with no single agent particularly dominant in this regard.

4.3 Type of Communications

Verbal exchanges between team members were not just recorded, transcribed and counted, but also categorised according to Bowers et al's (1998) taxonomy as being either:

- Factual: “objective statement involving verbalized readily observable realities of the environment, representing ‘ground truth’.”

- Meta-query: “request to repeat or confirm previous communication”.

- Response: “statement conveying more than one bit of information” (i.e. comprising of more than simply ‘yes/no’).

- Query: “direct or indirect task-related question”.

- Action: “statement requiring team member to perform a specific action”.

- Acknowledgement: “one bit statement following another statement (e.g., “yes”, “no”)”.

- Judgement: “sharing of information based on subjective interpretation of the situation” (Cuevas et al., 2006, p. 3-4).

Each individual category is analysed in terms of its relative contribution to the aggregate ‘total communication’ score using multiple regression (Warm, Dember & Hancock, 1996). Each category is ascribed a standardised beta coefficient that numerically expresses this contribution and enables the rank ordering shown in Table 4 below.

Table 4 - Standardised beta coefficients showing the relative factor loading of the individual communications categories within a regression model that assesses their contribution to total communications

NEC	C2
Response (0.36)	Acknowledgement (0.36)
Query (0.32)	Response (0.29)
Factual (0.22)	Action (0.26)
Acknowledgement (0.21)	Query (0.25)
Meta-query (0.17)	Meta-query (0.12)
Action (0.16)	Judgement (0.08)
Judgement (-0.06)	Factual (0.07)

The findings from this analysis show that NEC is not only relatively communications intensive and structurally different, but also that the communications flowing around the network are different in 'type' compared to the C2 condition. Taking the top three contributors it can be stated that the content of communications for the NEC condition is characterised by exchanges "conveying more than one bit of information", "direct or indirect task-related question[s]" and exchanges concerning the "readily observable realities of the environment". The C2 condition is characterised by one bit 'yes/no' statements and slightly elaborated versions of the same. It is also characterised by "statement[s] requiring team member[s] to perform a specific action". The effect of the hierarchical interactions and 'action based' instructions can clearly be seen.

5 Results Part 2: Meaningfulness of Tasks

Hypothesis 2 states that changes in the quantity, type and structure of communications will be accompanied by a corresponding change in the extent of task meaningfulness as measured by cohesion. The NEC condition should demonstrate higher levels of cohesion than the C2 condition. This section of the results analyses the data from this perspective.

Cohesion is a subjective experience of team working and an emergent property of the command organisations under analysis; like the other factors it is a product of the constraints of the organisation within which the team is working. The study was spread out over seven days and the fifteen item cohesion questionnaire was administered at the end of each day to every team member (this was the shortened version of the Combat Platoon Cohesion Questionnaire; Siebold & Kelly, 1988). The results were summed to provide a quick and simple measure of changes in subjective experience. Linear regression was used to diagnose the underlying model in the data. The results of applying this technique to the NEC cohesion data are promising. All the model diagnostics proved favourable. In the NEC condition team cohesion was strongly and significantly associated with trial interval ($r = -0.77$; $p < 0.05$), assumptions of linearity were supported ($F(1,5)=7.16$, $p<0.05$) and the regression model explained a substantial amount of the variance in the data ($R^2=0.59$). As Figure 3 shows, the intercept (b_0) occurred at a cohesion score of 61.43 (out of a maximum of 105) with the slope of the regression line (b_1) representing -1.86. Note that lower scores represent an improvement in subjective experience. As a result, the model suggests that the structural determinates of the NEC condition are associated with meaningful, linear improvements in the self-rated experience of those working within the constraints of the NEC organisation. The results for the C2 condition, on the other hand, are less promising.

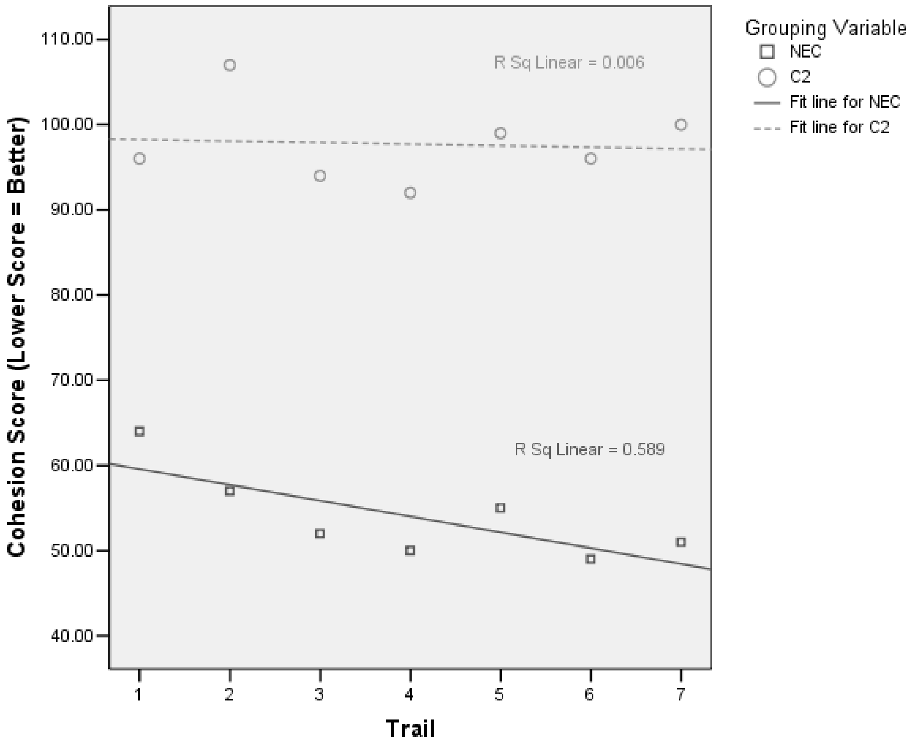

Figure 3 - Scatter plot showing the regression lines for both NEC and C2 conditions in relation to team cohesion

In the C2 condition the regression diagnostics suggest that there is little in the way of association between team cohesion and trial interval ($r = -0.08$; $p = ns$), assumptions of linearity are not supported ($F(1,5)=0.03$; $p = ns$) and the model explains next to nothing of the variance in the data (Adjusted $R^2 = -0.19$). Whilst team cohesion can be more than adequately modelled in linear terms for the NEC condition, with that model predicting meaningful improvements in team cohesion over time, the data for C2 is quite different: a similar, meaningful, linear relationship between team cohesion and trial interval does not exist.

6 Conclusions

It is often assumed that a networked info-structure, peer-to-peer working and effects based operations, amongst other structural determinates of NEC, will inevitably lead to self-synchronisation, and by implication, dramatic improvements in operational effectiveness. The current study was an opportunity to subject assumptions like these to a simple, direct test. Two hypotheses were put forward; firstly, that a simple command organisation designed around the tenets of NEC will lead to changes in the quantity, type and structure of communications compared to a C2 condition. The second hypothesis stated that these changes would be accompanied by a corresponding increase in cohesion (for the NEC condition). The results give grounds to support both propositions.

The results of the Social Network Analysis show that not only was the opportunity for peer-to-peer interaction taken within the NEC condition, but that it was associated with more communications and informationally richer ones too. Acknowledging the simplicity of the current scenario, it is nevertheless possible to conclude that in terms of NEC's first tenet, the networked organisation did indeed enable the widespread sharing of information and that the informational richness observed hints at improved quality of awareness (tenet #2). Further analysis is required to address this point more convincingly, however.

To set the present findings into context, earlier findings derived from the same experiment (Walker et al., 2008) can be introduced in order to help complete the picture. In this companion to the current report, self-synchronisation (tenet #4) was in evidence in the NEC condition as seen by the effective way in which the team set about organising themselves in the face of a dynamic adaptive opponent. One of the ways in which they did this was to engage pro-actively in peer-to-peer communication, effectively interpret effects based instructions in order to undertake the collaborative task in such a way as to balance and optimise task time, accuracy and the ratio of friendly to enemy captures. As for operational improvements, tenet #5, interestingly NEC did not increase tempo. C2, on the other hand, was able to optimise this single factor at the expense of other factors like accuracy but, as just mentioned, operational effectiveness in a dynamic and adaptive environment was demonstrated in terms of balancing several factors rather than merely optimising one. In this sense the NEC condition was exhibiting open systems behaviour. The key question, from a sociotechnical systems theory point of view, is whether this behaviour led to a corresponding improvement in terms of the subjective experience of those working under NEC conditions. In other words, is (or can) NEC be designed as a jointly optimised organisation?

Re-focusing now, from the wider picture onto the specific question of task meaningfulness, there was indeed structural evidence in the current study to suggest the presence of elevated levels of internal leadership and autonomy in the NEC condition. This conclusion can be based on the fact that sociometric status was much more evenly spread in the NEC condition compared to the C2 condition, for which a distended pattern of results emerged that favoured the commander. Did this structural evidence of task meaningfulness translate into a subjective experience of the same? The answer was yes. The behaviour of the cohesion measure in the NEC condition was considerably different to that obtained in the C2 condition. The results of the simple time series analysis show that the NEC condition creates the conditions for higher levels of cohesion from the outset, and improving levels thereon. By contrast, cohesion levels were low in comparison to the C2 condition and relatively static.

All of these findings ‘emerged’ from the study. They did so in the sense that they were not necessarily traceable to one individual component rather they arose as a product of a complex interaction, over time, of many. In effect, the study participants were provided with a set of initial conditions in the form of the safe houses microworld simulation and the hybrid socio and technical model was iterated numerous times in order to find out what happened. A brief consideration of the experimental context reveals the unique mix of tradeoffs and limitations and the success of the approach in detecting the properties for which it was designed.

Consider the first approach that could have been adopted, the formal experimental approach. In the present case this might have involved running the experimental (NEC) and control groups (C2) through a training intervention then measuring their social networks and cohesion just once. This one shot cross-sectional approach offers a considerable time saving, meaning that many more groups could have been put through the safe houses game in order to increase the certainty with which the findings could be generalised to a wider population. But what would the findings have been? Measured at time intervals 1 or 2, the quantity of communications would be reversed. C2 would emerge as measuring higher on this dimension than the NEC condition. Likewise, the structure and content of those communications changed markedly over time as did those for cohesion. Another disadvantage associated with the cross-sectional approach is the fact that it tends to rely on novice populations who never have the chance to become expert on the task because they only undertake it in anger once. This first approach, therefore, tends to downplay a fundamental property of open systems like NEC: time.

Consider the second approach, which would be to adopt the Monte Carlo simulations more traditional in the field of open systems research. Here, every part of the problem space could be modelled, the entire evolutionary space of the organisation allowed to unpack itself under all possible combinations of factors. The effect of time is amply captured. Yet the problem here is that the entities being modelled are simulated and artificial, decontextualising them from a military setting and preventing ostensibly human constructs like cohesion from being measured. This second approach struggles with further important properties of NEC: representing humans and the important aspects of a real-life military context.

The third approach answers this limitation and is prevalent in military settings, the ‘trial’ (or ‘field trial’). These are undoubtedly ecologically valid, lifelike and able to facilitate the measurement of human aspects of NEC. Unfortunately they tend to be one off affairs, with no control group(s) for comparison. Even when they occupy part of a series there is often so little experimental control that the progression from one trial to the next, experimentally, is very difficult to meaningfully compare. Data collection, too, tends to be limited and potentially intrusive. This third approach, therefore, finds ecological validity in conflict with experimental control.

Given its own set of practical constraints (i.e. time and resources) the current study set out to negotiate a path between these three different approaches, capitalising on the advantages of all three in terms of the problem space and the phenomena that are required to be measured. In terms of formal experimentation, the current study offers a high degree of experimental control (certainly compared to military trials). There is a matched control group, an explicit and repeatable set of initial conditions, and a focus on data collection and measurement. The main disadvantage concerns the small number of teams who took part (only one in each condition). To some extent this is governed by practical time/resource considerations, yet there is a more theoretical stance on this linked to the use of features from the modelling approach mentioned above.

Exposing the participants to an unusually high set of iterations through the scenario gives them the chance to become highly expert in its performance. Expertise connotes consolidation and convergence. In other words, it might be expected that whilst different teams would take their own evolutionary path through the problem space the data would still be attracted by the same emergent forces that drive the quantity of communications downwards for the C2 group, or else change the content and structure of communications. The use of a simple regression based approach to time series analysis is aimed at detecting gross patterns like this with some degree of statistical confidence. The question of how robust and/or universal these insights are is within the purview of future research. For the time being, the possibility of such dynamic and emergent phenomena is at least admitted.

The growing expertise of the participants in the study goes hand in hand with the microworld simulation. This approach aims to capitalise on the traditional benefits of military trials. To this end, what have been argued as key features of military settings have been preserved. Of course, a degree of simplification is necessary in order to ensure compatibility with a formal experimental approach and there are likely to be numerous details that would emerge in real settings that are not present here. Again, the use of simple statistical tools and a focus on the detection of gross emergent properties is aimed at ‘order of magnitude’ effects consistent with answering the broad experimental hypotheses posed by the research. The tricky issue for future research is the fact that as the system under analysis increasingly exhibits the properties of a complex system (with ever more interacting, contextually sensitive variables), the more ‘one of a kind’ it tends to become. A focus on gross patterns and relationships, notwithstanding a degree of simplification, appears to be a reasonable strategy at this level of analysis.

To conclude, the result of putting the structural and social determinates of command and control to a direct empirical test, albeit a simple one, is to illustrate that certain emergent phenomena arise from NEC and C2 organisations. NEC does indeed appear to create the conditions for a better human condition whilst working under its aegis. To that extent it is consistent with the sociotechnical literature in being jointly optimised; an important finding. The current study offers empirical support for some of the central assumptions driving forward the implementation of NEC, as well as assumptions concerning joint optimisation that are not yet conceived. Further work is directed at testing the universality of this evidence. As it is, the current findings are argued as representing an interesting advance on what existing approaches to experimentation have been able to inform us so far.

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