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Using an integrated methods approach to analyse the emergent properties of military command and control

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ABSTRACT

This paper applies the event analysis for systemic teamwork (EAST) method to an example of military command and control. EAST offers a way to describe system level emergent properties that arise from the complex interactions of system components (human and technical). These are described using an integrated methods approach and modelled using Task, Social and Propositional networks. The current article is divided into three parts: a brief description of the military command and control context, a brief description of the EAST method, and a more in depth presentation of the analysis outcomes. The emergent properties of the military scenario relate to the degree of system reconfigurability, systems level situational awareness and the role of mediating technology. The findings are compared with similar analyses undertaken in civilian domains, in which the latest developments in command and control, under the aegis of Network Enabled Capability (NEC), are already in place.

1. Introduction

Event analysis for systemic teamwork (EAST) is a macro-ergonomic method for extracting large scale systems level data on the emergent properties of command and control scenarios (e.g. Kleiner, 2006). The method is based on a number of observations: firstly, "effective team performance is not an automatic occurrence" (Salas et al., 1995, p. 55), secondly, increased complexity in military operations gives them the appearance of "different components and layers of subsystems with multiple non-linear interconnections that are difficult to recognise, manage and predict" (Marashi and Davis, 2005; Johnson, 2005, p. 1) and thirdly, the interaction of components and subsystems (teamworking + complexity) creates non-linear emergent properties at the level of the entire system. In other words, sociotechnical systems like this can be more (or indeed, much less) than the sum of their socio and technical parts. The challenge is to find ways to exploit complexity and non-linearity in order to "obtain a disproportionate leverage from a given action" (Smith, 2006, p. 40). Thus, focusing on the interrelations between command and control's component parts is perhaps as important as the parts in isolation. So, by shifting the unit of analysis from 'technical' to 'human', and shifting it again from 'individuals' to that of the 'system', and by deploying network based methodologies as a form of non-linear modelling, the data that EAST provides ultimately speaks towards this goal.

2. Description of command and control scenarios

2.1. Army land warfare and the combat estimate

The focus of this paper is on the application of the EAST method to military command and control, and the specific case of army land warfare. Land warfare (and other services) relies on a highly evolved planning heuristic called the combat estimate (or 'the seven questions') which form the topic of current EAST analysis. The Combat Estimate describes the process by which plans are made, expected outcomes are defined, and actions that then have to be taken.

In broad terms, Questions 1 and 2 are concerned with the development of situational awareness concerning the spatial configuration of the battlespace and of mission objectives. The specific

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activities undertaken in Question 1 include Battlefield Area Evaluation (BAE), which deals with the potential effects of the physical environment on military operations, and Threat Evaluation, assessing the enemy's capabilities and tactics. Question 2 is concerned with Mission Analysis and the scrutiny of orders that have been received. Questions 4–7, in equally broad terms, can be subsumed under the heading 'Course of Action Development'. Fig. 1 shows how the seven phases of the Combat Estimate relate to each other functionally and temporally. The diagram is a 'task network' based on the high level goals of a comprehensive hierarchical task analysis (HTA) of the scenario. The links between goals are specified by the HTA's top level 'Goal 0'.

2.2. Data collection

Data for the EAST analysis was gathered by live observation of command and staff training (CAST) exercises at the British Army's Land Warfare Centre in Warminster. The exercises took place in a Battlegroup command-post set up on-site as it would be deployed in the field. The command-post was set to work within a scenario which, in broad terms, required effects to be delivered to a large scale enemy force passing in one direction through the battlegroup's area of operations. Enemy and friendly units were simulated by a team of remotely located operators who provided a form of augmented reality, supplying friendly radio traffic (simulating units that would ordinarily be located in the field) and updating digital data pertaining to enemy movements, reactions and counter-actions. A team of analysts and subject matter experts monitored and transcribed video and audio feeds from the battlegroup headquarters. Key personnel active in the scenario were further interviewed at key points in the scenario using the Critical Decision Method (Klein and Armstrong, 2005).

3. Description of the EAST method

3.1. The importance of methods

The importance of Ergonomics methods cannot be overstated (e.g. Stanton et al., 2005a,b; Wilson and Corlett, 1995). Explicit methods lie at the heart of Ergonomics as a discipline, enabling the practitioner to vary their approach between scientist (i.e. testing and developing theories of human performance using rigorous data collection and analysis techniques) and practitioner (evaluating the effects of change, developing best-practice and, fundamentally, addressing real-world problems). Ergonomics methods are useful in the scientist-practitioner model because of the structure and potential for repeatability that they offer over and above informal methods.

3.2. Descriptive versus formative methods

The event analysis for systemic teamwork (EAST) method is based on the integration of seven individual Ergonomics methods. What appears to be a sizeable modelling endeavour is a reflection of the multi-faceted nature of the command and control problem to which it is designed to apply. No one method can adequately

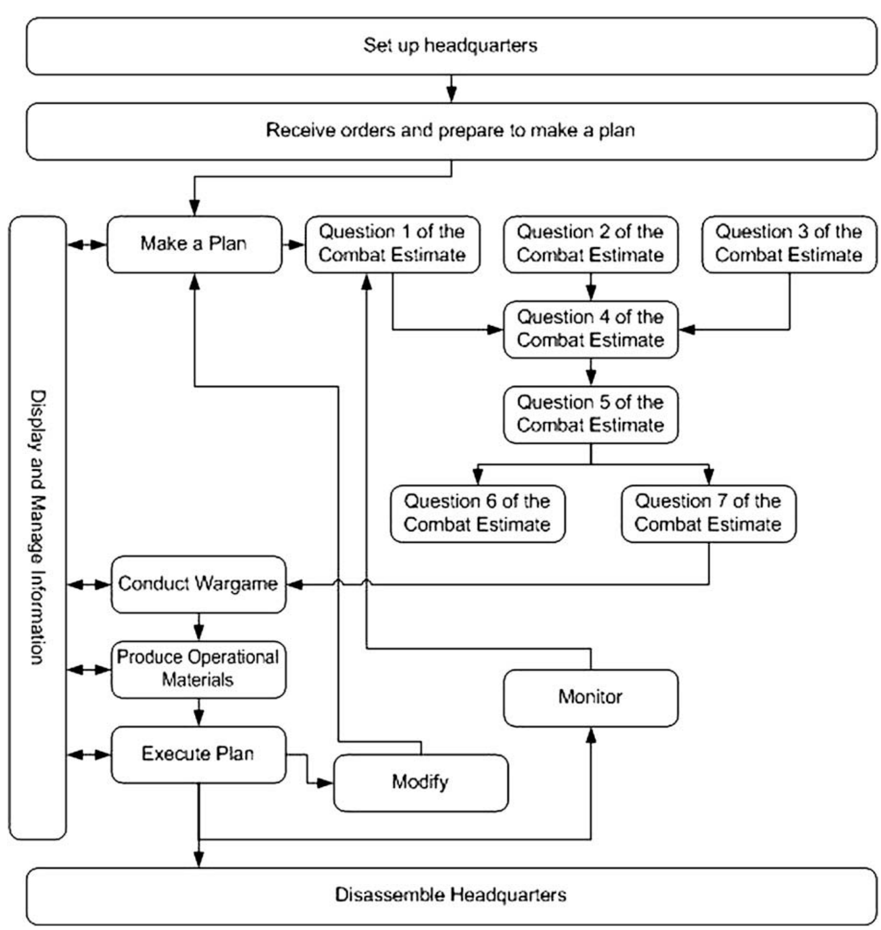

Fig. 1. Task network for the observed military command and control scenario.

describe all of the degrees of freedom inherent in such a complex sociotechnical system. No such claim is made for the EAST method; however, it can be argued that at least some of the major human dimensions of the problem space can be explored by taking a systems perspective on the diagnosis and description of 'what is going on' when command and control organisations are set to work.

EAST is a descriptive method. It does not specify a formal architecture and what 'should' happen. Even though it uses normative methods like task analysis and process modelling, they are populated based on what is actually observed. Neither does EAST focus on constraints, boundaries and a problem space defined formatively by what 'could happen' like cognitive work analysis (CWA; Vicente, 1999): EAST focuses on what 'did' happen. CWA admits the possibility of non-linear and emergent behaviour: EAST is designed to identify specific instances of it.

Despite their descriptive versus formative differences, EAST and CWA are both representative of a shift in methodological thinking. They share two key aspects: both acknowledge that complex sociotechnical systems require more than one approach (EAST is comprised of seven individual methodologies, CWA is comprised of five 'phases') and both acknowledge that these perspectives are as interlinked as the complex sociotechnical phenomenon under analysis (i.e. they are both systemic in nature). This is a core principle of sociotechnical design (Clegg, 2000).

3.3. Method integration

The following formal methodologies combine to form EAST: hierarchical task analysis (HTA: Annett, 2005), coordination demand analysis (CDA: Burke, 2005), communications usage diagram (CUD: Watts and Monk, 2000), social network analysis (SNA: Driskell and Mullen, 2005), propositional networks (PN: e.g. Ogden, 1987) and an enhanced form of operation sequence diagram (OSD: Kirwan and Ainsworth, 1992). A multiple method approach has a number of compelling advantages. Not only does the integration of existing methods bring reassurance in terms of a validation history but it also enables the same data to be analysed from multiple perspectives. With over 200 existing methodologies to choose from (Stanton et al., 2005a) there seemed little pragmatic need to develop yet more, hence the approach adopted, which was to integrate existing methods. The trade off, of course, is time. Multiple interconnected methods require greater effort to analyse but in some sense this is an artefact of the problem domain being analysed. Good news in this respect comes in the form of a companion to EAST called WESTT. This is a software tool that greatly streamlines and simplifies the application of the method and was used in the current analysis (Houghton et al., 2007).

The HTA provides input into the analysis of teamworking (CDA), communications usage (CUD) and the linkage (via communications) between agents (SNA). Data for the HTA is gathered from live observation and activity sampling as mentioned above. The output of all these methods (HTA, CDA, CUD and SNA) is given a summary visual form by using an enhanced operation sequence diagram (OSD). Interview data, in the form of the critical decision method (CDM: Klein and Armstrong, 2005), is used to create the final part of EAST, a network of linked 'information objects' (or propositional networks; PN). This is a systemic, network based approach to the concept of situation awareness (SA). The debates surrounding the concept of SA require more in depth discussion in relation to EAST.

3.4. Situational awareness

One of the key emergent properties from command and control scenarios, and one of the major determinants of decision superiority, is the concept of situation awareness (SA; Endsley, 1995; Salmon et al., submitted for publication; Stanton et al., 2006). At an individual level, SA is about simply 'knowing what is going on' (Endsley, 1995). At a systems level, SA enables decisions to be made in real time, and for sociotechnical systems like military command planning to be orientated towards and "*tightly coupled to the dynamics of the environment*" (Moray, 2004, p. 4). A distributed cognition perspective applied to command and control scenarios requires a shift from traditional notions of SA that focus on the individual (e.g. Smith and Hancock, 1995; Adams et al., 1995; Bedny and Meister, 1999; Endsley, 1995). Whilst these approaches may be appropriate for tasks that are performed by individuals in isolation, few complex command and control tasks are performed entirely independently of others. The idea of co-dependence in SA, of course, finds expression in several approaches to 'team SA' (e.g. Perla et al., 2000; Salas et al., 1995). Broadly speaking, these approaches to SA tacitly assume that the 'situation' can be defined as a single, objective, external reality, and that the goal of the people operating within the situation is to respond to all features appropriately. These approaches are problematic on three counts: first, there are many aspects of command and control scenarios that require the individual to make judgements and interpretations (so the assumption of the 'objective reality' of a situation is not always valid), second, there are multiple sub-goals and, therefore, multiple views of the situation (so the idea of a single reality is also not always valid either), and third, as mentioned above, different agents within the system use different pieces of information to inform and support their work, so the notion that there can be a single view of the situation (as opposed to several overlapping views) is not easily supported. Distributed cognition provides a way of coping with these conceptual issues and of providing a systems level view of SA (Salmon et al., submitted for publication). This view rests on three key factors.

1. Firstly, a relatively invariant theoretical property of SA concepts is 'information', in so far as "all aspects of momentary SA are eventually reducible to some form of [...] information in working memory" (Bell and Lyon, 2000, p. 42). Whether 'working memory' is an individual phenomenon (as implied by Bell and Lyon, 2000) or whether it is a 'system-level' representational state (as implied by the notions of Distributed Cognition); for the purposes of the current EAST analysis, the latter, more contentious view is taken.
2. Secondly, the 'information' that underlies distributed SA is itself distributed, across the entire system, including non-human artefacts that can create, manage and share representational states. This means that the system will be managing the exchange of aspects of representational states through the passage of information between agents.
3. Third, there is often implicit transaction of information rather than a conscious hand-over or exchange. Thus, the update of a representational state for one agent might lead to partial updating of that used by another, and this might not be the result of communication that is managed by human agents (or might not require detailed information processing by any of the agents). For example, as an enemy force element moves across a sector its route is plotted on the various map displays and its position updated dynamically; if there is little immediate risk, then the updating happens without a corresponding need for intervention or overt 'awareness'.

The concept of situational awareness, therefore, looks rather different from a 'distributed' as opposed to individual perspective. It is still about the dynamic orientation of a system to its operational context but the units of analysis centre around information, as opposed to individuals (and the psychological processes by which the state of SA is achieved). Information is held, exchanged, represented and transformed by human and non-human agents, its propagation is supported by whatever communication infrastructure is currently in place, managed by the underlying Control structure, and evaluated by the underlying Command activity.

Information objects, defined as entities or phenomena about which an 'agent' in the system requires information in order to act effectively, are extracted from the CDM interview transcripts using content analysis. Causal links between objects are established in order to create the propositional network. The totality of information residing at the systems level, when modelled as an interconnected web of information, can be viewed as 'systemic SA'. Different parts of the system use/share different items of information, different items of information, when active, relate to yet more information that is connected to it, the whole configuration of usage and sharing in turn changes dynamically in response to the context. (A considerable body of related work on this topic is provided in Walker et al., submitted for publication.)

3.5. Theoretical basis

The combination of observation and interview, analysis and representational methods, forms EAST. A more detailed description of how the specific method outputs are derived is provided in the next section (as well as in Walker et al., in press). A summary of EAST, and how its component methods relate to each other functionally, is shown below in Fig. 2.

EAST is a human centred approach but one whose component methods are all anchored to a common systems perspective. This is manifest in a number of underpinning ideas, principle among which is distributed cognition. Under this perspective the 'computations' that comprise military command and control are not the exclusive province of individuals (Rogers, 1997; Hollan et al., 2000; Hutchins, 1995) instead they are distributed across the entire command and control system, comprised of numerous individuals, teams and technical artefacts. The essence of Distributed Cognition is on "how [these computations] transcend the boundaries of the individual actor" and to this end the common language of representational states is used. Representational states are visible and external manifestations of various 'environmental contributions' to the total system (Fields et al., 1998; Rogers and Ellis, 1994). They subsume the full range of observable interactions between people and artefacts, as well as the resulting states (and state changes) that arise. In essence, the focus of the EAST method is on describing artefacts that relate to:

1. the changes that are made to these representational states,
2. their influence and promulgation around a distributed network of human and non-human actors and
3. in turn, how that influence generates new changes to representational states.

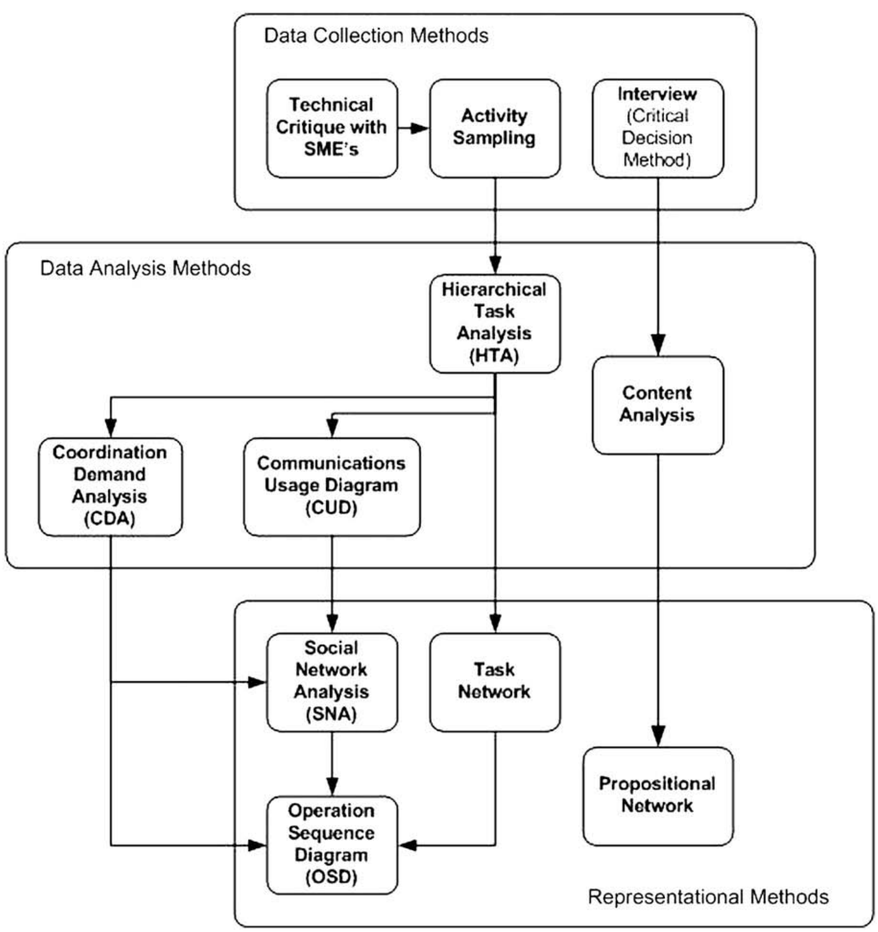

Fig. 2. Structure of the EAST method.

4. Findings

4.1. Coordination demand analysis (CDA)

According to Salas et al. (1995), "the military is growing increasingly dependent on the ability of individuals to coalesce quickly into effective teams" (p. 55). Therefore, it might be assumed that command and control scenarios will be dominated by teamwork activities but this supposition can be checked in more detail. The coordination demand analysis (CDA) procedure allows for the identification of teamwork skills needed for smooth coordination among team members. Individual tasks from the HTA were categorised into task or teamwork tracks (e.g. Salas et al., 1995; Morgan, 1986). The teamwork tasks were then scored against the CDA taxonomy of: communication, situational awareness, decision making, mission analysis, leadership, adaptability and assertiveness (Burke, 2005). Each CDA taxonomy item was scored from 1 to 3 where 1 is low coordination and 3 is high coordination. From these individual scores a 'total coordination' figure can be derived which is based on the mean of the component scores. In this scenario, the scoring was derived from a focus group comprised of the analyst team and subject matter experts. Each item was briefly discussed and its final score based on consensus among the group. Overall, the mean total coordination score for the military scenario is 1.2 (out of a maximum score of 3). This score is broadly comparable to civilian command and control domains like air traffic control (e.g. Walker et al., in press), railway signalling and safety operations (e.g. Walker et al., 2006) and bulk energy distribution (e.g. Salmon et al., 2008). The mean coordination score was also calculated for the seven main stages of the HTA (these represent the phases in the military scenario) and the results are shown in Table 1.

The supposition that command and control activities have a prominent teamworking component is well justified, as would be expected, yet different phases of the planning process require different types and amounts of teamwork; the CDA provides a window on to this. The scores for the individual coordination dimensions vary across the full range of permissible values. It can be noted that communications and situation awareness score consistently highly, whereas decision making scores relatively low. This and other facets of the team working profile could arise because the decision making components of the scenario are constrained by hierarchical patterns of interaction, pre-specified forms of interaction and/or unitary decision rights (NATO, 2006). This pattern differs from the civilian examples mentioned above where the EAST method has been applied. Here, the decision making and planning phases tend to occur concurrently and continuously (as opposed to a relatively discreet stage) and where decision making scores more highly.

4.2. Communications usage diagram (CUD)

Current military command and control activities do not necessarily have a particularly complex communications infrastructure in place compared to the various forms 'Network Enabled' versions of command and control seen in other domains. Network enabled capability (NEC) is an emerging paradigm whereby a pervasive information infrastructure is created which, combined with greater autonomy and a focus on teams and task outcomes, offers considerable potential to impact all the human and organisational parameters currently under analysis. For example, experience in the energy distribution domain reveals a recent development that sees 'peripatetic working' (focusing on autonomous and mobile teams) and the extensive use of tablet PC's and a dedicated information infrastructure (Salmon et al., 2008). Indeed, EAST is motivated to a great extent by the growing demands of this emerging paradigm. The value in assessing an ostensibly non-NEC military scenario like the current one is to establish a form of baseline.

The advent of NEC technology like advanced communications and data networks has an immediate impact on communications, therefore, its proximal effects are likely to be seen first in this particular sub-method, the Coms Usage Diagram (CUD). In the current scenario the military planning process involves verbal dialogues between planning personnel in close proximity (during meetings), and announcements in which the command staff will shout (e.g. timescales for upcoming meetings or deadlines). Radio communications are also an integral part of mediating voice communications and take the form of verbal dialogues using a standardised radio telephony method. Communications within the command centre are, therefore, conducted principally by voice. Having said that, the final group of communications media are the operational materials produced out of the planning process, along with visual aids such as whiteboards and clear overlays that are used during it. All of these communication methods can be analysed using the communications usage diagram (CUD).

The CUD contains a description of the activity conducted at each geographical location, the communication between actors involved, the technology used for the communications, the advantages and disadvantages associated with that technology medium and a recommended technology, if there is one. The CUD method, therefore, is a structured way to represent communications within a scenario based on task flow (and thus the HTA). For the purposes of this paper the method output has been synthesised into a list of advantages and disadvantages (Table 2) followed by a critique of communications usage.

Table 1
CDA analysis results according to task phase.

Category	Prepare plan	Display & manage information	Combat estimate (make plan)	Translate products of Q1-7 into operational graphics	Conduct war game	Execute plan
Mean comms	2.5	2	2.2		2	3
Mean SA	2	2	2.2		2	2
Mean DM		1.5	1.8		1	2
Mean MA	1	2	2.1		1	1
Mean leadership	1.25	1.3	1.6		2	3
Mean adaptability		2	2		3	2
Mean assertiveness			1.8		1	2
Total coordination	1.7	1.8	2.0	0	1.7	2.1

4.2.1. Advantages and disadvantages of existing comms. media

Table 2

Media	Advantages	Disadvantages
In-person voice	Physical verification that correct individual (and planning role) is being referred to.	Possible detrimental role of social status/military rank.
	Favourable role of non-verbal communications in aiding shared understanding.	Possible contextually related distractions (e.g. noise and general confusion in the command centre).
	Possible favourable role of military rank in face to face communications.	Possible ambiguity in physically pointing out and referring to shared resources (e.g. plans and whiteboards).
	Sharing of explanatory resources such as operational graphics/whiteboards, etc.	Relatively static descriptions of a highly dynamic and spatially dispersed scenario.
Radio communications	Sound stable.	Intelligibility can be an issue with distortion/artefacts in radio comms.
	Possible for communications to be recorded for post-hoc analysis and training.	Language/accent ambiguities.
	Hands free.	Unscheduled/ad-hoc presentation of comms.
	Time saving with common abbreviations and nomenclature.	Any informality/abbreviation in comms. relies on assumption of shared meaning.
	Enhanced intelligibility with common abbreviations and nomenclature.	Relatively slow communications compared to other comms solutions.
	Read-back provides validation of shared understanding.	Translation from verbal domain to visio spatial domain required (and vice versa).
	Open channel radio comms. aids shared SA among other units and members of planning staff.	Open channel radio comms. could permit simultaneous comms. on same frequency causing masking.
	Possibly favourable dilution of group-think/military rank artefacts on communication and comprehension errors.	Read-back can be out of synchronisation with current activities if sender/recipient are slow to respond.
		Unfavourable dilution of favourable aspects of military rank.
Operational graphics and planning aids	Paper based materials can be substantially degraded without information loss.	Static representations of typically dynamic scenarios.
	Relatively easy to derive with little extra training required in having to use a pen and paper.	Training load relatively high in the use of methods to overcome the disadvantages of representing dynamic 3D phenomena as 2D paper based representations.
		Complexity and dynamism of scenario can cause administrative bottlenecks.
		Legibility of graphics and handwriting.
		Whiteboards and overlays potentially cumbersome to handle.
		Document tracking and administration potentially difficult.

4.2.2. Critique of comms. usage

The survey of advantages and disadvantages forms part of a structured means to describe and critique existing communications technology. It should be added that the critique is not indicative of any actual or proposed recommendation, rather it is a consideration of possible alternatives and issues based on the data collected.

4.2.3. Verbal communications

A compelling advantage of verbal communications is the level of immediacy and redundancy it provides. De Carvalho (2006) states that, "…operators use verbal exchanges to produce continuous, redundant and recursive interactions to successfully construct and maintain individual and mutual awareness" (p. 51). There remains, however, the possibility of psychological issues such as 'group-think' and bias in using this form of communication in this context, although there are techniques available to help overcome this (Janis, 1982a,b). It can be noted that verbal communications also dominate in civilian command and control scenarios.

4.2.4. Network enabled solutions

Gaining situational awareness of the battlespace, a key aspect of the Combat Estimate, requires a number of transformations to be undertaken in order to represent and to understand the state of the world. Voice, written and 2D imagery in the planning process all needs to be visualised, and then acted upon in four dimensional space (3D plus time). Cognitive effort is required, therefore, to achieve adequate levels of situational awareness from which to develop and resource courses of action. Thus, there is a lot of 'information in the head', which can be advantageous for situational awareness. NEC approaches that embody positional data, 3D representations of the battlespace and live updating of it directly from the field, embody considerably more 'information in the world'. The task of air traffic control, for example, would be virtually impossible to conduct at its current tempo without the sort of visualisation and live updating provided by the radar display; although even here the representation is two dimensional. An issue that emerged from the CUD and CDA methods was that the combat estimate 'process' was often just as important as the 'outcome'. For example, a considerable degree of teamworking was devoted to developing SA. In addition, scrutinising the supporting communications methods using the CUD reveals advantages as well as prima-facia disadvantages of what could be considered simplistic planning apparatus.

4.3. Social network analysis (SNA)

Social network analysis (SNA) is a means to present and describe the underlying network structure of individuals or teams who are linked through communications (Driskell and Mullen, 2005). Social networks focus "[…] on the relationships among actors embedded in their social context" (Driskell and Mullen, 2005, p. 58.1). NEC concepts embody a form of information comodification, thus social networks can be used to represent the technological mediation of communication and networks where some of the nodes are non-human. The resulting network can then be subject to mathematical analysis using Graph Theory in order to simplify it and express its

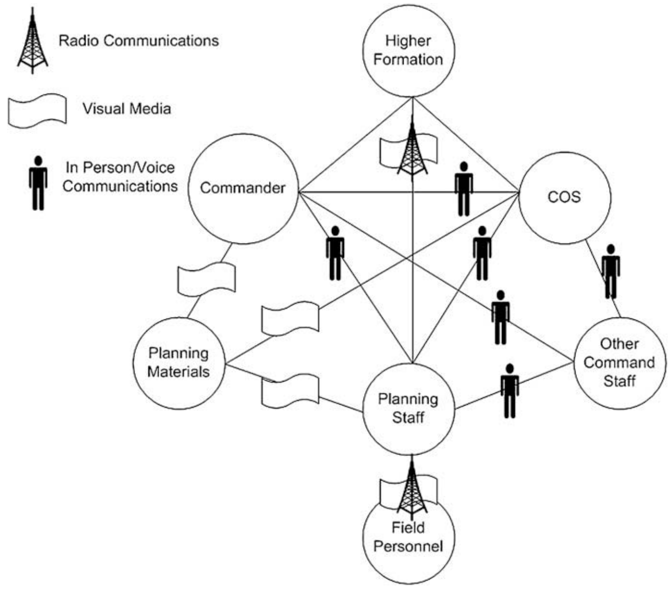

Fig. 3. Social network for military command and control scenario (icons represent the communications media that facilitates the linkage).

key features in a standardised form using a numeric index (Driskell and Mullen, 2005). Two mathematical indices are used, namely 'centrality' (i.e. a numeric ranking allowing key agents in the network to be identified) and 'density' (the interconnectivity of the network as a whole). Both of these metrics can be understood in relation to other contextual factors to enable judgements to be made about what aspects of the network configuration constrain or enhance performance. The metrics, being emergent properties of the networks as well as a means to simplify them, permit easy comparison between alternate domains.

The social network for military command and control defines seven key actors, some of which have been grouped into subsystems for simplicity (as illustrated in Fig. 3). The actors or nodes include the Higher Command Formation, the Commander and Chief of Staff (COS) at the command headquarters, the 'Principal' Planning Staff (which subsumes individual roles such as G2 Intelligence and EngGeo), other command staff (responsible for more general tasks and information management), personnel in the field, and the collection of graphics and planning aids derived from the Combat Estimate process (an informational node that is non-human).

4.3.1. Activity stereotypes

The social network is dynamic and adaptive with different nodes and links becoming active under different activity stereotypes (revealed by detailed analysis of the HTA). The activity stereotypes are as follows:

Table 3
Technology/facilitation/modality matrix.

Modality	Technology/facilitation		
	Radio	Planning aids	In-person voice
Verbal	×		×
Visual		×	×
Written		×	

"×" represents a match between communications technology and communications modality.

- *Briefing or providing direction:* the Commander is directing communications and ccprescribed and tightly coupled manner (particularly Questions 1 and 3 of the Combat c).
- *Reviewing:* the planning staff communicate in a more collaborative, peer-to-peer manner, with mutual exchange of information and ad-hoc usage of planning materials and outputs (in particular Questions 2 and 5 of the Combat Estimate).
- *Semi-autonomous working:* members of the headquarters are working individually on assigned tasks and become relatively loosely coupled in terms of communication. The communication channels remain open but are used in an ad-hoc, unprescribed manner (this occurs at various points in all phases of the Combat Estimate, and the scenario more generally).

The temporal and task based activation of agents and communications, in which they assume different stereotypical configurations is illustrated in Fig. 4.

4.3.2. Facilitation of network links

Fig. 3 also illustrates the communications media that facilitate the links between nodes in the network. These are formally defined by the CUD method above. The results are also summarised in Table 3 as a communications/modality/technology matrix. A cross indicates where a specific communications technology is crossed with a specific modality. The matrix appears to be relatively simple in the observed military scenarios. A heavy reliance on verbal information, which occurs in person and via radio, was noted. There is also heavy reliance on visual communication, as embodied by the various planning aids. In-person communications, it was noted, also incorporates visually mediated communication as staff point and gesture at maps and planning aids. Although simplistic compared to other civilian examples of NEC (like air traffic control) the underlying social and communications system is undeniably robust. Similar robustness might be regarded as a redundant and, indeed, inefficient feature in civilian contexts. Clearly, there are opportunities, for example, to more rapidly acquire the state of situational awareness through novel technology that does not necessarily rely on verbal communications and manual updating of maps. Such a system is realised in

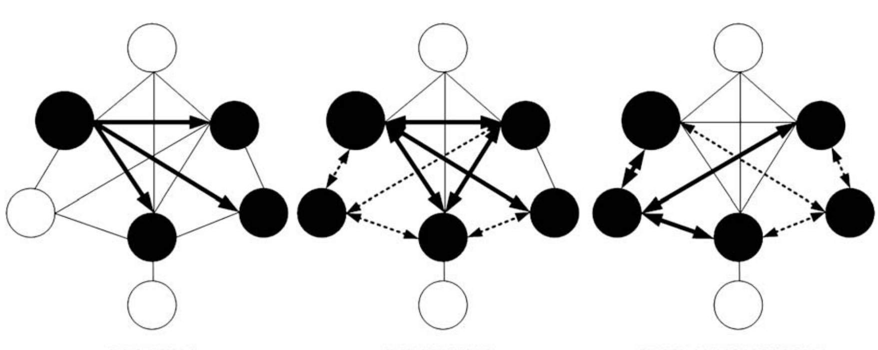

Fig. 4. Social networks illustrating the characteristics of a number of network archetypes detected in the analysis (to be read in conjunction with figure 3).

Table 4
Network metrics illustrating centrality (key agents in the scenario) and density (network connectivity) for the social network as a whole.

Agent	Agent centrality	Network density
Higher formation	0.89	0.31
Commander	1.11	
COS	1.11	
Other command staff	0.67	
Principal staff	1.33	
Field personnel	0.22	
Planning materials	0.67	

the civilian examples of air traffic control (Walker et al., submitted for publication) and energy distribution (Salmon et al., 2008), in which the resulting social networks show, in comparison, a much denser interconnection between actors using a more diverse array of technology to facilitate the kind of redundant, recursive interactions that are required in high tempo tasks. Table 3 is based on Fig. 3 (which in turn is based on the CUD method above) and shows the communication modality that is afforded by the various items of communications technology in the scenario. It is interesting to note that the dominant communications modality is well supported; it is further interesting to note that future digitisation of military command and control is likely to expand the visual and written modalities somewhat more than it will the verbal modality.

4.3.3. Calculation of social network metrics

The 'most central agents' are revealed, by network mathematics, to be the principal planning staff, followed by the commander and chief of staff (Table 4). In NEC scenarios, it might be anticipated that the spread of centrality scores will be less pronounced as a result of more devolved decision rights and peer-to-peer interaction and this is certainly evident in civilian examples. The network density figure of 0.31 is suggestive of a moderate level of connectivity within the network and is again comparable with civilian examples. The point here is that the total number of available communications links is more or less the same, but that they are configured differently in NEC paradigms. These links define the structure of the network and also its function.

Table 5 presents the results of this analysis, showing how the properties of the network change to reflect the stereotypical ways in which it is configured. The change in network density for each activity stereotype is also indicative of a high degree of reconfigurability. This appears to be a relatively unique feature of military command and control. In civilian examples, the network density figures do not change as dramatically as the task progresses through its distinct phases. The reason is due to the complexity inherent in the operational context. Both civilian examples operate within a relatively stable and placid environment in contrast to the turbulent and complex military one.

4.4. Operation sequence diagrams (OSD)

The operation sequence diagram (OSD) is the main descriptive summary representation within the EAST method. It is an activity based representation showing who is performing what, when. Using colour coding, symbology and annotation, the OSD can represent most of the critical features of the preceding methods on one common representation. There is insufficient space to present the full OSD analysis of the current scenario, but an opportunity remains to present a small sub-set of the charts in order to reflect on the more distinctive overall features of the analysis so far.

The sample OSD in Fig. 5 illustrates many of the facets dealt with in earlier methods. Team working and coordination is reflected not only by the explicit colour coding of operations (darker shading denotes higher levels of total coordination) but also in the varying patterns of connectivity between and among operations (represented by the symbols). The social network stereotypes are also represented by the configurations of links and operations. For example, in the earlier phases of the Combat Estimate (more Briefing activities) there is a focus on the hierarchical/vertical flow of information, with the Commander producing it and other agent's Receiving it. In the second phase (more Reviewing activities) the operations (and agents) become closely interconnected, with decision making components dominating (shown by the diamond symbol(s)). In the third and final phase (more Semi-Autonomous working), the pattern of operations once again assumes a vertical/hierarchical disposition. At the highest level, then, the command and control process seems to assume a pattern of information retrieval, closely knit decision making processes and then dispersion and action.

4.5. Propositional networks (PN)

From the CDM interview it is possible to construct propositional networks (PN; an example of which is shown in Fig. 6) to show the information that is related to the scenario. The propositional network consists of a set of nodes that represent sources of information, agents and objects that are linked through specific causal paths (for example, the object [situation] 'has' the property of [updates] associated with it, and so on). As mentioned earlier, these objects are extracted from the CDM interview transcripts using content analysis. The deeper, more fundamental concept that this method refers to is situational awareness (SA), an important concept in decision making, agility and tempo. The advantage of the propositional network approach is that it represents a way of modelling the information that comprises the state of SA, from an individual as well as systems perspective. In addition, because it is network based, it meshes with the social and task networks that form the basis for the rest of the EAST method. From the propositional network it is possible to identify: the structure and temporal nature of distributed SA (explained in full in Stanton et al., 2006) and the information underpinning decision making.

Table 5
Network metrics illustrating centrality (key agents in the scenario) and density (network connectivity) for the activity stereotypes of briefing, reviewing and semi-autonomous working.

Agent	Centrality			Density		
	Briefing	Reviewing	Semi-autonomous	Briefing	Reviewing	Semi-autonomous
Higher formation	×	×	×	0.03	0.20	0.13
Orders	×	×	×			
Commander	0.33	0.67	0.33			
COS	0.11	0.67	0.33			
Other command staff	0.11	0.33	0.33			
Principal staff	0.11	0.67	0.33			
Field personnel	×	×	×			
Planning materials	×	0.33	0.67			

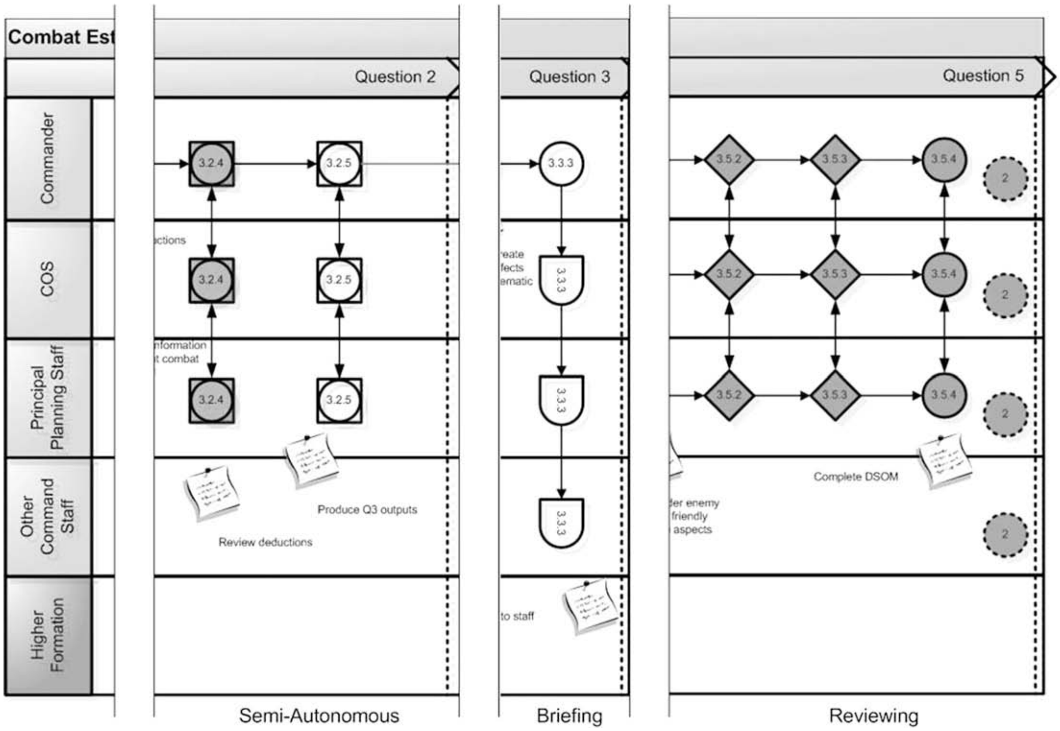

Fig. 5. Sections through the complete OSD chart for military scenario showing (left to right) semi-autonomous working, briefing and reviewing.

The summary table (Table 6) uses simple graph theory metrics (as used in the social networks above) to summarise the visually complex network(s) into a more tractable form. Based on an analysis of centrality, so-called 'core information objects' can be defined for each phase in the scenario (a CDM interview was carried out in relation to each phase, as was a separate propositional network). The table crosses each phase of the Combat Estimate planning technique with the list of core information objects. A "cross" denotes specifically what information objects are active in what phase. These core information objects also feed back up to the CUD method earlier. Their prescription enables an analysis of what information objects are shared between what agents and, therefore, require some form of communications technology to mediate the sharing. In the CUD method the appropriateness of this match forms one aspect of the basis by which communications technology is, and can be, critiqued

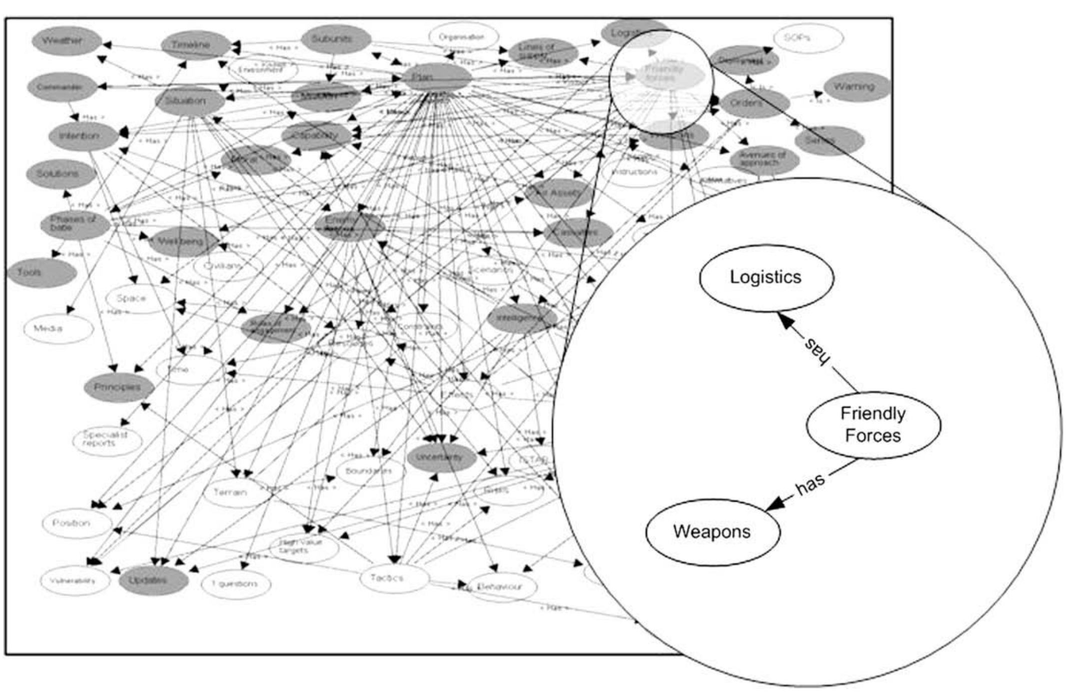

Fig. 6. Illustration of propositional network representing a systems level view of information but also temporally activated informations for a particular task phase (shaded objects). The overall network is presented for illustration; the 'zoomed' section shows some of the detail.

Table 6
Summary table of key information objects active within each scenario.

Key information objects	Q1	Q2 & 3	Q4	Q5	Q6	Implementing plan
Subunits		×			×	×
Plan		×	×		×	×
Friendly forces		×	×	×	×	×
Orders		×		×	×	×
Situation	×	×		×	×	×
Intention	×	×	×		×	×
Capability	×	×			×	×
Phases of battle					×	
Weapons		×			×	
Enemy		×	×	×	×	×
Intelligence	×		×	×	×	×
Effects		×	×	×		
Courses of action		×			×	×
Uncertainty	×				×	
Terrain	×	×		×		
Position	×					
Tactics	×					
History	×			×		
Total information objects	9	12	6	8	13	10

× indicates what information is specifically active during what stage of the combat estimate.

(see Walker et al., in press for an in depth treatment of how this specific approach can be realised).

Eighteen key information objects can be identified. As the Combat Estimate planning process progresses through its distinct phases, it can clearly be seen that the activation of these key objects changes. This is further indicative of changes in the type and structure of the propositional network and in the type of situational awareness possessed by individuals and the system as whole. This information can be used to assess the extent to which the system is orientated towards the dynamics of its situation as well as identifying information requirements for different tasks and scenarios.

5. Conclusions

The principles of human factors integration (HFI) encompass "…a balanced development of both the technical and human aspects of equipment provision. It provides a process that ensures the application of scientific knowledge about human characteristics through the specification, design and evaluation of systems." (MoD, 2000, p. 6). The EAST method is couched firmly within this context. It is, at bottom, a way of capturing and describing the human view of complex sociotechnical systems, not what should or might happen when they are set to work, but what actually does happen. Being based on the integration of seven existing Ergonomics methodologies the outputs are structured, systematic and standardised. The validation history that is associated with each of them brings the promise of repeatability and compatibility across situations and even domains.

The aim of the present analysis has been to demonstrate the applicability of the method within military contexts, which represent a particularly challenging and complex command and control environment. The analysis has been couched at a fairly coarse grained level of analysis, anchored as it has been to the discrete phases of the combat estimate planning process. As much (or as little) resolution can be extracted dependent upon the questions being asked and analysis effort that is willing to be expended. For the purposes of presenting EAST's human view of military command and control, and how those insights map across to other domains, the present level of analysis seems appropriate.

What does this application of the EAST method tell us? It tells us about the structural and temporal nature of the goals and tasks that have to be performed and how they are interlinked and interdependent. The structure of the task network (like any system) defines its function. In the case of the military, it is noted not just that there is a defined 'planning phase' but that it is relatively sequential and recursive in nature. In the civilian domains that have been observed previously, planning, at least at strategic and operational levels, tends to occur concurrently with the task; 'on the fly' so to speak. That said, in civilian domains the sociotechnical system's combined experience (of which it is an evolutionary expression) and its generally placid environment, enables rule based optimum means to ends to be learnt and rapid decision making to take place.

It can be noted that the function of the social networks also changes, they are reconfigurable (and readily reconfigured) to suit the task phase, often in ways that are not anticipated before hand. This is, therefore, an emergent property of the interaction between the task and social networks. The links in the social network are informational and the content of this information is represented by the propositional network, a representation that captures systems level information and, we argue, situational awareness. Situational awareness is once again an emergent property of both the task and social networks. In particular, the way in which the social network is configured dictates the informational constraints placed on it by the facilitating communications technology. Overall, it is clear that cognition is distributed between socio and technical agents in the scenario. This, combined with the fact that the socio elements (the people) will adapt the technical elements to suit their needs and preferences, contributes to a degree of self-organisation and emergence which is apparent through analysis with EAST.

EAST's three main network representations, illustrated in Fig. 7, are an analytical response to complexity and emergence, but from a uniquely human perspective. A key point is that EAST acknowledges the sociotechnical principle of equifinality, that the same people and the same technology may reach the same goal by entirely different means and from entirely different initial conditions. This is not a conceptual inconvenience but actually one of the very promises of NEC. The inviolable fact that humans will adapt to the techno-organisational properties of a given system is what permits desirable emergent properties to 'emerge'; like systems level 'shared awareness', tempo, agility and self-synchronisation. EAST seems to offer a way to capture and describe this in a way that deterministic (i.e. linear) methods may not.

Driven off the higher level network representations are a number of more explicit methods that relate more directly to requirements capture. In the CUD, for example, task and social networks combine to inform a structured assessment of

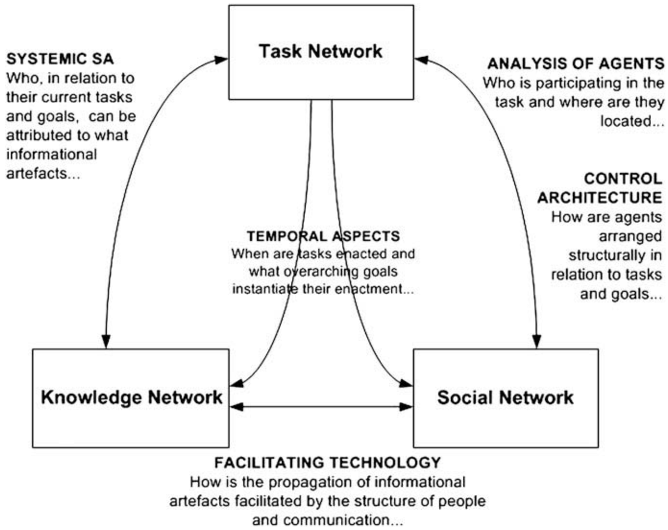

Fig. 7. Summary of EAST's three network based perspectives and the insights into emergent properties that they provide.

communications technology. This analysis is further informed by the notions of distributed SA that are embodied in EAST. In other words, it becomes possible to assess what purpose a communication exchange is designed to serve, what information it is designed to convey, and moreover, what would be the best means of facilitating that exchange. In addition to this, the CDA method highlights certain important aspects of teamworking at different phases of the planning process. This sort of information is useful in the design of digital command planning systems. For example, there would be little point in providing 'decision support' for a planning phase that is actually revealed as requiring more 'mission analysis'. The benefits of the interlinked EAST method are that changes in any of the three underlying network representations (task, social and propositional networks) are reflected in each other and in the supporting methods like CUD and CDA. The disadvantage of the EAST method, at least at face value, is the amount of time it takes to perform such an analysis. The reader is referred to a companion software tool called WESTT that greatly simplifies and streamlines the application of EAST, automating many functions, notably the production of the various task, social and knowledge networks (Houghton et al., 2007).

In conclusion, EAST is offered as a means to describe the dynamic, emergent behaviour of complex sociotechnical systems from a human perspective. It appears consistent with wider trends in Ergonomics towards method integration and systems views, and is eminently compatible with similar approaches like CWA. The aim of the present high level analysis has been to illuminate some of these wider issues and the applicability of EAST to military contexts. More targeted forms of application will enable EAST to provide more targeted and direct answers to design and procurement questions in an age when the critical networks in NEC are not necessarily technological but human.

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