A Human Factors Approach to Analysing 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 Knowledge 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. Numerous findings emerge from the application of the method. These findings are compared with similar analyses undertaken in civilian domains, where Network Enabled Capability (NEC) is already in place. The emergent properties of the military scenario relate to the degree of system reconfigurability, systems level Situational Awareness (SA), team-working and the role of mediating technology. It is argued that the EAST method can be used to offer several interesting perspectives on designing and specifying NEC capability in military contexts.

KEYWORDS

C4I, EAST Method, NEC, Situational Awareness, Teamwork, Communications.

INTRODUCTION

Emergent properties exist where the *"characteristics of the whole are developed (emerge) from the interactions of their components in a non-apparent way"* (Bar Yam, 1997). It reflects a focus on the systems level (that of aggregate behaviour) rather than the structural level (and the behaviour of individual components). Emergent behaviour arises out of synergy, which is the product of interaction at a component level. Arguably, the goal of any command and control system is to maximise this synergistic effect (Stanton et al., 2005).

Command and control scenarios are a particular analytical challenge. They are an instance where people and technology form a joint cognitive system (Hollnagel, 1993) so that *"When the [structure] is put to work, the human elements change their characteristics; they adapt to the functional characteristics of the working system, and they modify system characteristics to serve their particular needs and preferences"* (Rasmussen, Petjerson & Goodstein, 1994). Although the affect of a central agency is particularly acute in command and control scenarios (by their very nature there are shared goals, an organisational infrastructure, set procedures and so forth) they still cannot precisely specify many of the emergent properties that arise from this 'unspecified' adaptation, nor arguably, the multiplicative effects of synergy. It can be stated that the type and structure of many emergent properties, such as SA, team-working and communication, arises as much out of 'unspecified adaptation' as it does from structural or procedural determinates of a system. It can also be stated that many of these systems level phenomena cannot be traced back in their entirety to an individual agent, therefore precluding them from analysis with the majority of Human Factors techniques.

The Event Analysis for Systemic Teamwork (EAST) method provides a means to undertake an analysis of any command and control scenario from a systems perspective and to characterise some of the emergent properties alluded to above (e.g. Stanton et al., 2005; Walker et al., In Press a & b). The locus of the current article is around an EAST analysis of military command and control but the results are situated within a wider context. This is achieved by comparing the military domain with EAST analyses carried out previously in the civilian domain (specifically Air Traffic Control and energy distribution). The defining features of these two classes of scenario is that one, military command and control, does not embody the principles of Networked Enabled Capability (NEC), whereas the other, civilian command and control, does. The current paper undertakes an exploration and analysis of four properties that can be said to be (to some extent at least) emergent, namely: SA, team-working, communications and system reconfigurability. The results are intended to provide an illustration of the network-based EAST method outputs; SA relates to the outputs of knowledge networks, team-working relates to the outputs of task networks, and communications relates to the outputs of social networks.

DESCRIPTION OF OBSERVED MILITARY SCENARIO

Sources of Data

The study team collected data for the EAST analysis from the following:

- Observation of Command And Staff Training (CAST) exercises at the British Army's Land Warfare Centre in Warminster between 11th and 15th July 2005.

- Observation of military decision making and planning training on the 2nd and 3rd August 2005 at the Land Warfare Centre in Warminster.
- Observation of a Fire Power Demonstration on the 11th October 2005 at the British Army's range on Salisbury Plain.

The majority of the observed scenarios took place in a Battlegroup command post set up on-site. A team of analysts and a subject matter expert monitored and transcribed video and audio feeds from a remote location. Key personnel active in the scenario were further interviewed at key points in the scenario using the Critical Decision Method (Klein & Armstrong, 2005).

The Combat Estimate

The observed scenarios were subsumed by a military planning process called The Combat Estimate (MoD, 2005b). This describes the process by which "an adequate and flexible plan is developed in a reasonable amount of time" (MoD, 2005b). In summary form the Combat Estimate is described in terms of 'seven questions', by which the process itself is often referred. These are as follows:

Question 1 – "What is the enemy doing and why?"

Question 2 – "What have I been told to do and why?"

Question 3 – "What effects do I want to have on the enemy and what direction must I give to develop my plan?"

Question 4 – "Where can I best accomplish each action/effect?"

Question 5 – "What resources do I need to accomplish each action/effect?"

Question 6 – "When and where do the actions take place in relation to each other?"

Question 7 – “What control measures do I need to impose?”

In broad terms, Questions 1 and 2 are concerned with the development of situational awareness/understanding about the spatial configuration of the battlespace, and of mission objectives. Question’s 4 to 7, in equally broad terms, can be subsumed under the heading 'Course of Action Development'. As mentioned above, the observed military scenario(s) cannot be said to conform to an NEC paradigm. The enactment of the Combat Estimate technique is supported by a rudimentary (although undeniably robust) technological infrastructure; namely paper maps, acetate overlays, written materials and radio communications. Figure 1 shows how the main phases of activity, and the seven individual ‘questions’ of the Combat Estimate, relate to each other functionally and temporally. The diagram is called a ‘task network’ and is based on the higher level goal structure of a comprehensive Hierarchical Task Analysis (carried out as the first stage of an EAST analysis).

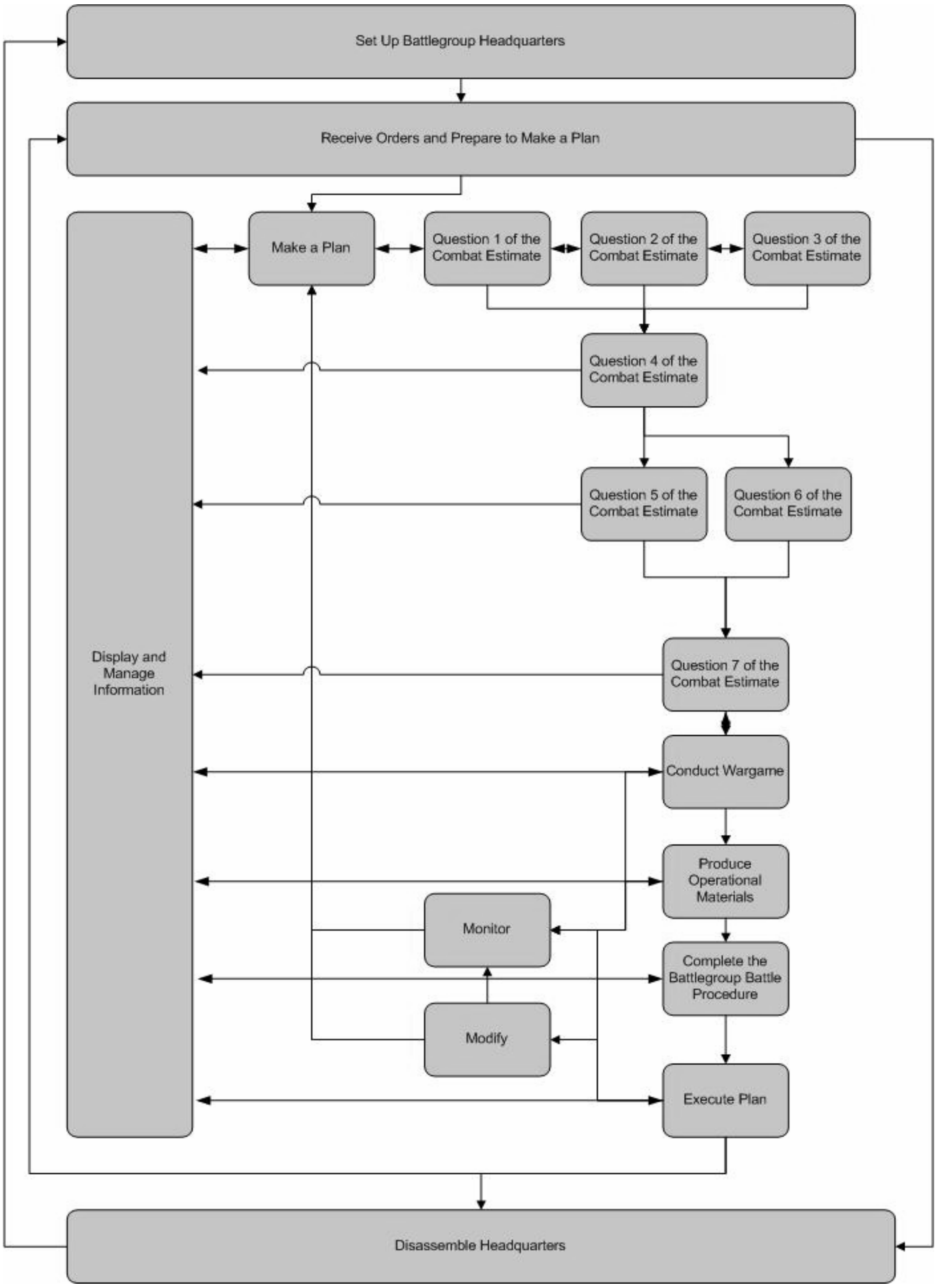


Figure 1 – Task network for the observed military command and control scenario.

DESCRIPTION OF THE EAST METHOD

The EAST method is based on the integration of seven individual Ergonomics methods. Methods integration of this kind has a number of compelling advantages; not only does it bring reassurance in terms of a validation history, but it also enables the same data to be analysed from multiple perspectives. These multiple perspectives are argued to be inherent in any joint cognitive system, and indeed, are required to be analysed in order to extract and describe the non-apparent emergent properties that arise from such systems.

The following individual methods combine to form EAST: Hierarchical Task Analysis (HTA: Annett, 2005 [see Figure 1 above]), Coordination Demand Analysis (CDA: Burke, 2005), Communications Usage Diagram (CUD: Watts & Monk, 2000), Social Network Analysis (SNA: Driskall & Mullen 2005), Knowledge Networks (KN: e.g. Ogden, 1987) and an enhanced form of Operation Sequence Diagram (OSD: Kirwan & Ainsworth, 1992). The component methods link to each other (procedurally) in the manner shown below in Figure 2. The primary outputs of EAST are network based, they take the form of Task Networks, Social Networks and Knowledge Networks (Figure 3). The interplay between these networks provides a number of compelling insights into the systems level emergent properties of command and control scenarios, and forms the structure for the current article.

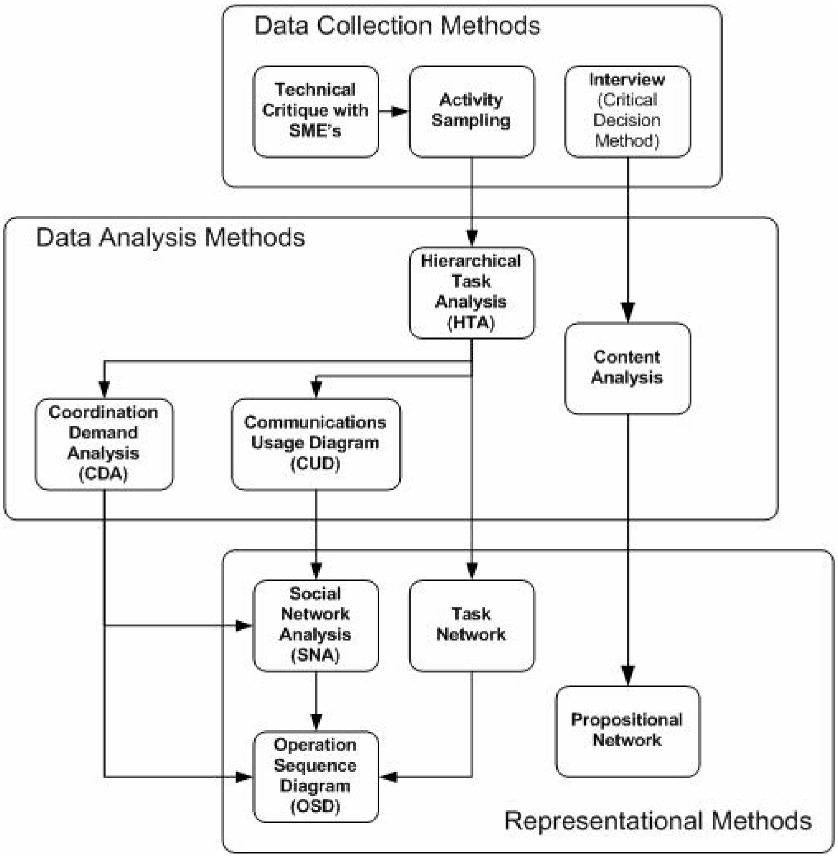


Figure 2 – Structure of the EAST method.

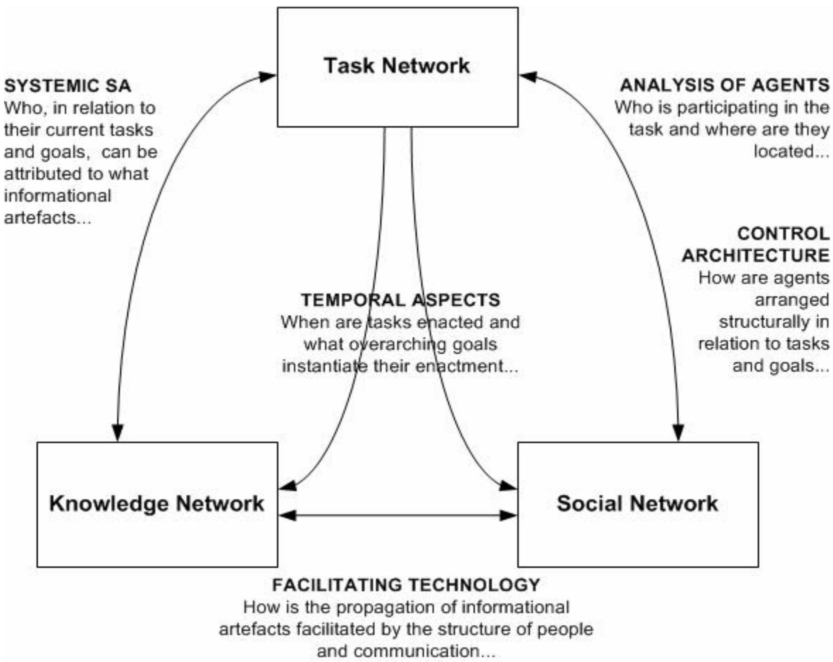


Figure 3 – Conceptualisation of the EAST method's network based outputs (and linkages between them)

FINDINGS

Data Derived from the Task Network (Team-working)

The task analysis is used, in this case, to extract and compare emergent properties related to team-working. It might be assumed that command and control scenarios will be dominated by coordination activities, but this supposition needs to be checked using the Coordination Demand Analysis (CUD) method (Burke, 2005). Individual tasks from the HTA were categorised and scored against the CDA taxonomy of: communication, situational awareness, decision making, mission analysis, leadership, adaptability and assertiveness (Burke, 2005). Each CDA taxonomy item is 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 (based on the mean of the component scores).

Overall, the mean total coordination score for the military scenario is 1.6 (out of a maximum score of three). Despite large differences in the command structure and supporting technical infrastructure, total coordination in the military scenario appears to be comparable to both civilian (NEC) examples. Where military and civilian scenarios differ is in the relative proportions of task and teamwork activities. Task work is performed in isolation, teamwork requires coordination with others. The military scenario shows an almost even split (48%/52% respectively), which differs from air traffic control scenarios (more autonomous working with a 65/35 split respectively) and energy distribution (more team-working, with a 30/70 split respectively). For additional probity the mean co-ordination score was also calculated for the seven main stages of the HTA (these represent temporal phases in the military scenario) and the results are shown in Table 1.

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 Wargame	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

The scores for the individual coordination dimensions vary across the full range of permissible values, from one through to three. It can be noted that communications and situation awareness score consistently high, whereas decision making scores relatively low. This pattern differs from civilian examples in which the decision making and planning phases tend to occur concurrently and continuously (as opposed to a discreet stage). As a result, coordination scores remain stable across task phase. Based on these results the supposition that command and control activities have a prominent team-working component is justified, but different domains (NEC versus non-NEC) possess different teamwork characteristics.

Data Derived from Social Network Analysis (Reconfigurability and Communications)

Social network analysis is a means to present and describe the underlying network structure of individuals or teams who are linked through communications (Driskell & Mullen, 2005). Social networks focus "[…] on the relationships among actors embedded in their social context" (Driskell & Mullen, 2005, p. 58-1). Social networks can be used in a novel way to try and represent the technological mediation of communication, and joint cognitive systems in which some of the nodes are non-human. The resulting network (Figure 4) can be subject to mathematical analysis using Graph Theory (Driskell & Mullen, 2005) to derive two numerical indices: 'centrality' (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.

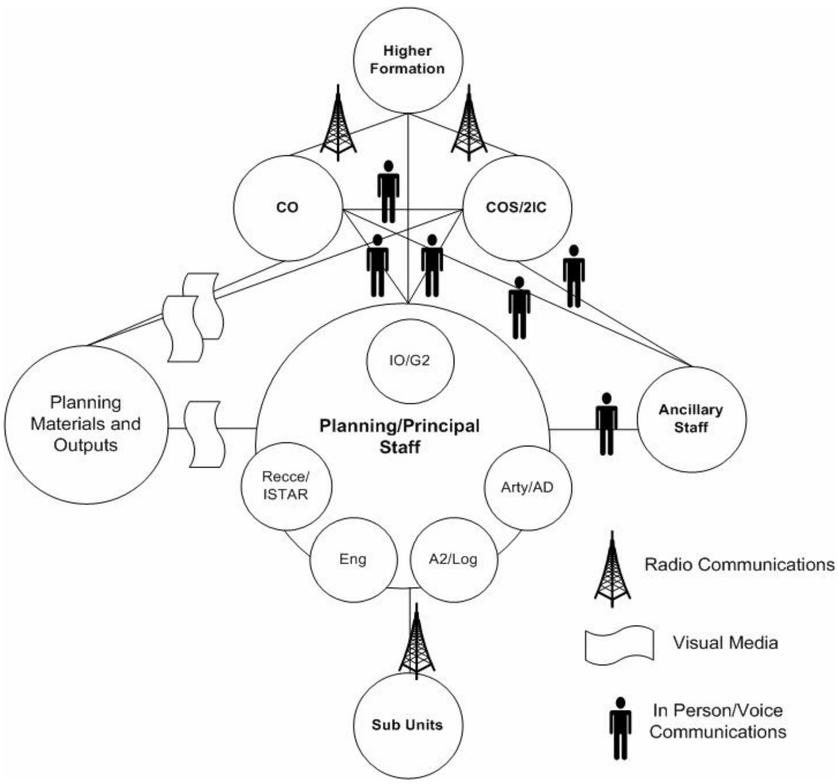


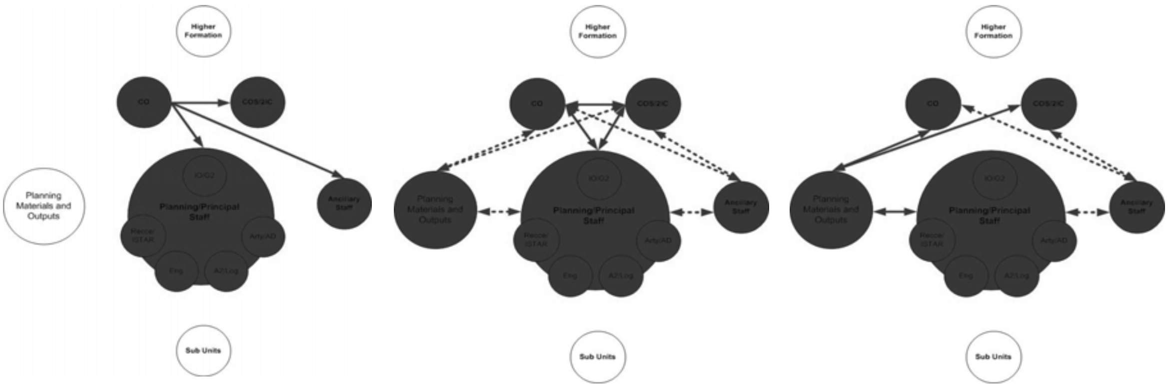
Figure 4 – Social network for the military command and control scenario showing how agents in the scenario are configured in relation to each other and the communications links that exist between them.

System Reconfigurability

The social network is dynamic and reconfigurable; different nodes and links become active under different activity stereotypes. Activity is defined and modelled by the Task Network above and the network reconfigures itself as follows:

- Briefing or providing direction: the Commander is directing communications and information outwards to subordinate staff in a prescribed and tightly coupled manner (particularly Questions 1 and 3 of the Combat Estimate planning technique).
- Reviewing: the planning staff communicate in a more collaborative 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, un-prescribed manner (this occurs at various points in all phases of the Combat Estimate).

The temporal and task based activation of agents and communications, in which they assume different stereotypical configurations, is illustrated in Figure 5.



Briefing | Reviewing | Semi-Autonomous Working

Figure 5 – Illustration of the changing configuration of the social network in respect to three distinct activity stereotypes (to be read in conjunction with figure 3).

Communications

Figure 4 also illustrates the communications media that facilitate the links between nodes in the network. These are formally defined by the CUD method and summarised in Table 2 as a communications/modality/technology matrix. Shading indicates where a specific communications technology is crossed with a specific modality. The matrix appears to be relatively simple in the military scenarios, being dominated by verbal communication. The trade-off is towards robustness (a highly desirable feature in military contexts). Similar robustness might be regarded as a redundant and indeed inefficient feature in civilian contexts. Clearly, there are opportunities to, for example, more rapidly acquire the state of SA through novel technology that does not necessarily rely on verbal communications and manual updating of maps. Such a system is realised in the civilian examples of air traffic control and energy distribution, in which the resulting social networks show, in comparison, a much denser interconnection between actors using a more diverse array of technology.

Table 2 – Technology/Facilitation/Modality Matrix. Shading Represents a Match Between Communications Technology and Communications Modality

	Technology/Facilitation		
Modality	Radio	Planning Aids	In-Person Voice
Verbal	■		■
Visual		■	■
Written		■	

Calculation of Social Network Metrics

The 'most central agents' are revealed by network mathematics to be the planning/principal staff, followed by the commanding officer and COS/2IC (Table 3). In NEC scenarios it might be anticipated that the spread of centrality scores will be less pronounced as a result of greater interconnectivity and information sharing; this is certainly evident in both civilian examples. Further in depth analysis would reveal whether the uneven spread of centrality scores in the military domain is a favourable reflection of command (and authority) or a potentially risky situation in which information bottlenecks arise. The network density figure of 0.31 is suggestive of a moderate level of connectivity within the network, and is again comparable with both civilian examples. Perhaps 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.

Table 3 - Network metrics illustrating centrality (key agents in the scenario) and density (network connectivity) for the social network as a whole.

Agent	**Agent Centrality**
Higher Formation	0.89
Commanding Officer	1.11
COS/2IC	1.11
Ancillary Staff	0.67
Planning/Principal Staff	1.33
Sub Units	0.22
Planning Materials & Outputs	0.67
NETWORK DENSITY	0.31

The change in network density for each activity stereotype is also indicative of a high degree of reconfigurability. Table 4 presents the centrality results reflecting the different ways in which the network is configured. This appears to be a relatively unique feature of military command and control. One possible explanation is that a high degree of flexibility, the need to adapt to new situations and a discrete planning phase, arises out of the range of possible military effects combined with the dynamism of the operational context. In comparison, the civilian examples are working within (relatively) tightly constrained environments, with the emphasis very much upon 'minimising system disturbances', 'maintaining equilibrium' and 'maximising safety'. A more static configuration of people and technology may be desirable in such circumstances.

Table 4 – Network metrics illustrating centrality (key agents in the scenario) and density (network connectivity) for the activity stereotypes of Briefing, Reviewing and Semi-Autonomous Working.

		Centrality	
Agent	Briefing	Reviewing	Semi-Autonomous
Higher Formation			
Commanding Officer	0.33	0.67	0.33
COS/2IC	0.11	0.67	0.33
Ancillary Staff	0.11	0.33	0.33
Planning/Principal Staff	0.11	0.67	0.33
Sub Units			
Planning Materials		0.33	0.67
NETWORK DENSITY	0.03	0.20	0.13

Data Derived from Knowledge Networks (Systems Level SA)

From the CDM interview it is possible to construct Knowledge Networks (an example of which is shown in Figure 6) to show the knowledge that is related to the scenario. The 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 knowledge objects are extracted from the CDM transcripts using content analysis. The deeper, more fundamental concept that this method refers to is, of course, SA. The advantage of the knowledge network approach is that it represents a way of modelling the knowledge 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 knowledge network it is possible to identify: the structure and temporal nature of distributed SA (explained in full in Stanton et al., In Press), and the knowledge underpinning decision making.

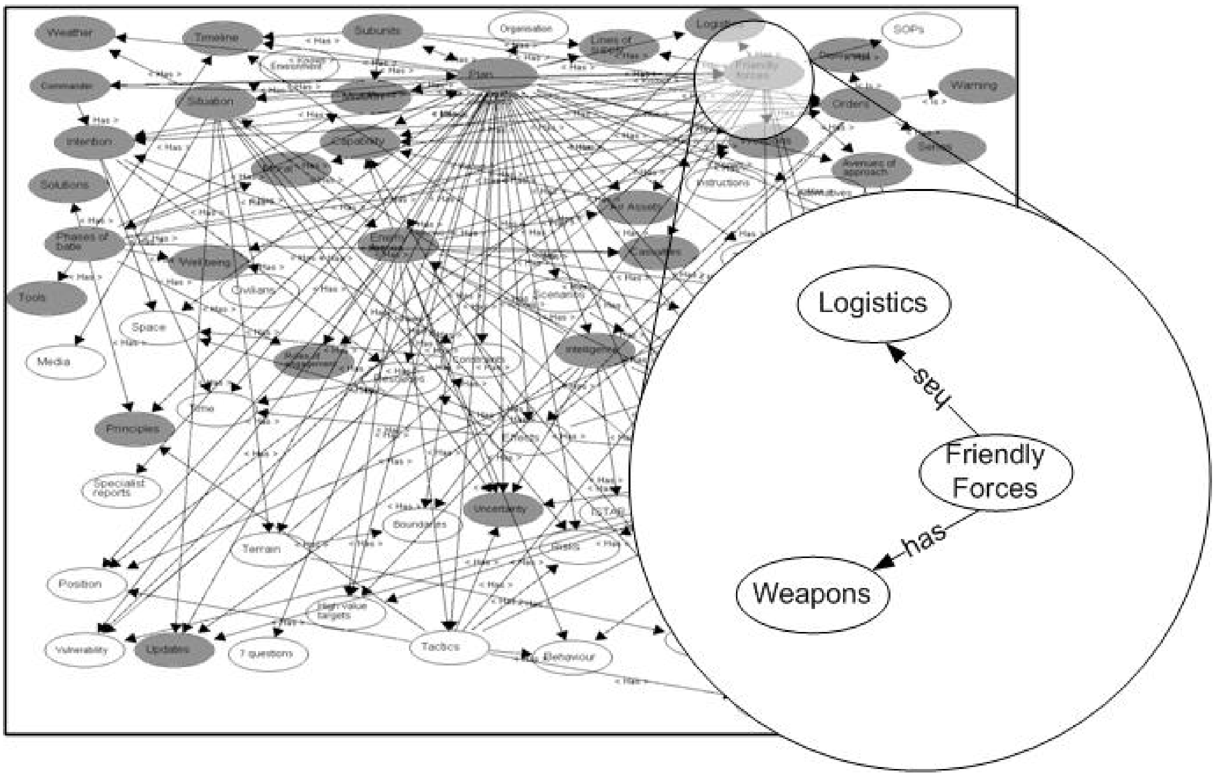


Figure 6 – Illustration of knowledge network representing a systems level view of knowledge but also temporally activated knowledge for a particular task phase (shaded objects). The overall network is presented for illustration; the 'zoomed' section shows a small section in detail.

The summary table (Table 5) uses simple graph theory metrics to summarise the visually complex network(s) into a more tractable form. Based on an analysis of centrality, so-called 'core knowledge 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 knowledge network). The table crosses each phase of the Combat Estimate planning technique with the list of core knowledge objects defined earlier. Shading denotes specifically what knowledge objects are active in what phase. These core knowledge objects also feed back up to the CUD method earlier. Their prescription enables an analysis of what knowledge 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 (see Walker et al In Press a for an in depth treatment of how this specific approach can be realised). Such an approach has implications for the design and specification of NEC paradigms.

Table 5 - Summary Table of Key Knowledge Objects Active Within Each Scenario. Shading Indicates What Knowledge is Specifically Active During What Stage of the Combat Estimate.

Key Knowledge 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 Knowledge Objects	9	12	6	8	13	10

Eighteen key knowledge objects can be identified. As the Combat Estimate planning process progresses through its distinct phases, it can be seen that the activation of these key objects changes. This is indicative of changes in the type and structure of SA at the systems level It can be seen that objects referring to uncertainty, terrain, position and tactics predominate in the early phase of the process, whereas intelligence and courses of action dominate later phases (with friendly forces, situation and enemy dominant throughout). The advantage of this approach, certainly at this high level of analysis, is that it pinpoints the changing sources of information that actors in the scenario draw upon to develop SA. Systems level SA, of the sort modelled by the knowledge network, is emergent to the extent that no one actor or agent has the property of 'systemic SA' residing within it. It is a product of synergy and component interaction. The more pragmatic benefits of such an approach is that it provides a new perspective on the specific knowledge based facets that personnel require training in.

CONCLUSIONS

Military command and control is a highly complex domain. This paper, therefore, is necessarily couched at a summary level of analysis and based upon observation of three particular instances. The results require interpretation with those caveats in place, but in so far as generalisations and characterisations can be made, the following emergent properties and issues have arisen from the current EAST analysis:

1. Military command and control relies heavily on tasks that require interaction with other team members, and where this is manifest, team-working is principally concerned with the communication of information and development of SA. Thus, the task network can be seen to link to the knowledge network.
2. A relatively simple, yet robust, technological infrastructure underpins team tasks. It is heavily reliant on a combination of verbal communications and/or the translation of various planning 'products' into an integrated, collective, 4D spatial and temporal 'image' of the battlespace. It appears to be in this domain, based on the CUD method,

that NEC technology has much to offer. The assumption is that if the state of SA can be more rapidly and accurately acquired (and there seems little doubt that new technology offers this potential), then decision superiority can be achieved more quickly. If SA can also be shared in optimal ways throughout the system (which again, new technology appears to provide for), then unity of effort can also be achieved.

3. The HTA specifies how the configuration of people and technology changes in a task and context dependant manner (thus the task network also links to the social network, and vice versa). Three activity stereotypes are defined; semi-autonomous working, briefing and reviewing. The network configures (and re-configures) itself numerous times during the enactment of the Combat Estimate. As the network is re-configured, the constraints of it in terms of communications, density and centrality change. The design of NEC paradigms, therefore, is revealed to be more than just a consideration of technology in isolation. The specification of technology may be appropriate for one configuration, but inappropriate for another. The combination of HTA and SNA appears to provide one route into addressing this issue.

4. The knowledge base that underpins effective SA at the systems level changes in response to task phase (linking knowledge networks to task networks), but also arises as a property of the constraining features of the configuration of people and technology (linking knowledge networks to social networks). Systems level SA, at this summary level of analysis, appears to support and be congruent with task goals (as specified by the HTA).

In summary, the emergent properties associated with military (and indeed any) command and control scenario relate to the interplay between task, social and knowledge networks. An attempt has been made to illustrate that interplay as it relates to non-NEC military command

and control whilst contextualising the results within a broader setting of civilian scenarios where NEC is already in place.

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