WESTT (Workload, Error, Situational Awareness, Time and Teamwork): An analytical prototyping system for command and control

Robert J. Houghton[1], Chris Baber[1], Malcolm Cowton[2], Neville Stanton[3] and Guy Walker[3]

[1] *Electrical, electronic and computer engineering,*
School of Engineering, The University of Birmingham,
Birmingham, B15 2TT, United Kingdom.
Tel: +44 (0) 121 414 3141
Fax: +44 (0) 121 414 4291
R.J.Houghton@bham.ac.uk C.Baber@bham.ac.uk
http://www.eee.bham.ac.uk/eece/ / http://www.hfidtc.com

[2] *Aerosystems International, Yeovil, United Kingdom.*
[3] *School of Engineering and Design, Brunel University, United Kingdom.*

Abstract

Modern developments in the use of information technology within command and control allow unprecedented degrees of flexibility in the way teams deal with tasks. These developments, together with the increased recognition of the importance of knowledge management within teams present difficulties for the analyst in terms of evaluating the impacts of changes to task or team composition. In this paper we present an approach to this problem that represents team behavior in terms of three linked networks (task, social and knowledge networks) that we have instantiated within the integrative WESTT software tool. By automating many analyses of workload and error we furthermore allow the user to engage in the process of rapid and iterative 'analytical prototyping'. In addition, we also present an example of the use of this technique with regard to a proposed tactical vignette.

Keywords: Analytical prototyping, command and control, network enabled capability, social networks, knowledge networks, human error, workload.

Introduction

The field of command and control (C2) is undergoing significant changes as the result of the gradual adoption of information and networking technologies. Indeed, so profound are these coming changes that it is argued that the adoption of Network Enabled Capability (NEC) as it is termed in the UK, will transform the way in which UK armed forces operate: “It offers a new way of not just “doing things better” but of “doing better things”” (MoD, 2005). It is envisaged that NEC, by linking sensors, effectors, decision makers and other individuals will through the rapid and timely sharing of information create widespread shared understanding of a situation that will in turn allow swifter actions, based on better-informed decisions, to be made (MoD, 2005). Another benefit of NEC will be increased flexibility and agility within teams as a result of flexibility within information sharing and communications to create: “…highly responsive, well integrated and flexible joint force elements that have assured access to and unprecedented freedom of manoeuvre within the entire battlespace.” (MoD, 2004). Clearly then, whilst NEC will be based on the roll-out of technology, the locus of its effect will be upon human cognition and decision making to enable better actions to be made (see Houghton & Baber, 2005).

This situation created by the adoption of NEC technology poses considerable challenges for the analyst hoping to understand and evaluate the sociotechnical systems it produces: First, the emphasis on agility and flexibility suggests that standard approaches to Human Factors techniques may be too time-consuming to produce useful guidance; rather a system of rapidly modeling and then reconfiguring team performance is required. This general approach is termed analytical prototyping and is based on the concept that initial system descriptions can be quantatively explored in order to evaluate the potential benefits of modification (Baber & Stanton, 1999, 2001) Second, the importance attached to the fluid possession and sharing of information prompts us to need to find a way of usefully representing and understanding the distribution and use of information within the sociotechnical systems that NEC will create. Our proposed solution to this problem takes the form of linking knowledge objects to individuals and tasks to produce a systems-level rendering of knowledge use. Third, the integration of sensors, effectors and humans suggests the requirement for the production of a systems-level depiction of NEC that considers the interaction of both humans and technological items. Our approach to this issue is to represent all entities as “agents” within the system that have essentially the same characteristics whether human or non-human (that is, they can possess and share knowledge and carry out certain tasks or operations). By adopting this approach one can therefore investigate the impacts of augmenting or even replacing elements of teams with new technology on a like-for-like basis and in terms of how they contribute to the system as a whole.

In addressing the foregoing issues and allowing analytical prototyping the WESTT (Workload, Error, Situational Awareness, Time and Teamwork) software tool has a range of possible applications that are not necessarily limited to the military sphere. These include the analysis of field data and the evaluation of current practice; comparison between actual performance and design/doctrine; evaluation of changes to current practice through modeling; and evaluation of performance in training and virtual environments. Whilst our approach has been motivated primary with regard to military operations, but we believe the WESTT tool can be used widely in the study of any organization where C2 and complex team/collaborative performance are important elements (e.g., Police, Fire, Ambulance activities and commercial logistics operations). It is to be noted that whilst WESTT is an integrative approach, bringing together many metrics and modes of representation of team activity one is by now means required to necessarily use all of its elements; for example for a specific purpose WESTT may be usefully employed to generate, say, social networks and error measures alone.

Underlying approach

Key to the design of WESTT is the contention that, with the advent of network-enabled systems and the increased acknowledgement of the importance of knowledge management in war fighting, fully understanding C2 performance requires an appreciation of what happened in a given situation or scenario from at least three distinct but closely interrelated perspectives: the tasks being performed by the team, the nature of the social network the team is acting within and the knowledge being used and exchanged. Thus we suggest that C2 and team activity are best understood as being the product of a tightly coupled networks and structures wherein the examination of one network requires knowledge of the structure of the others. This interrelation is depicted in Figure 1.

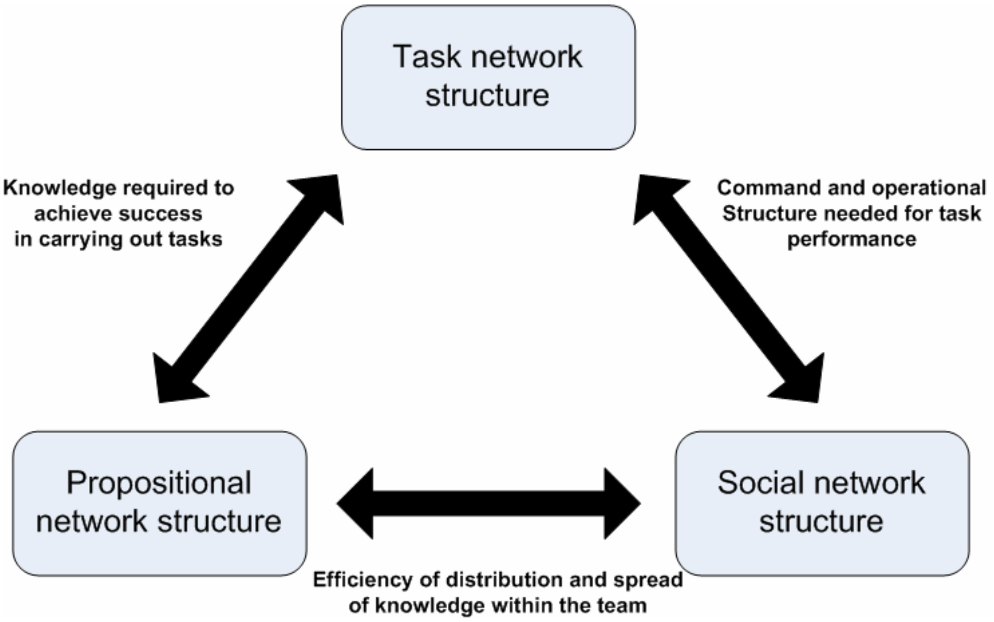


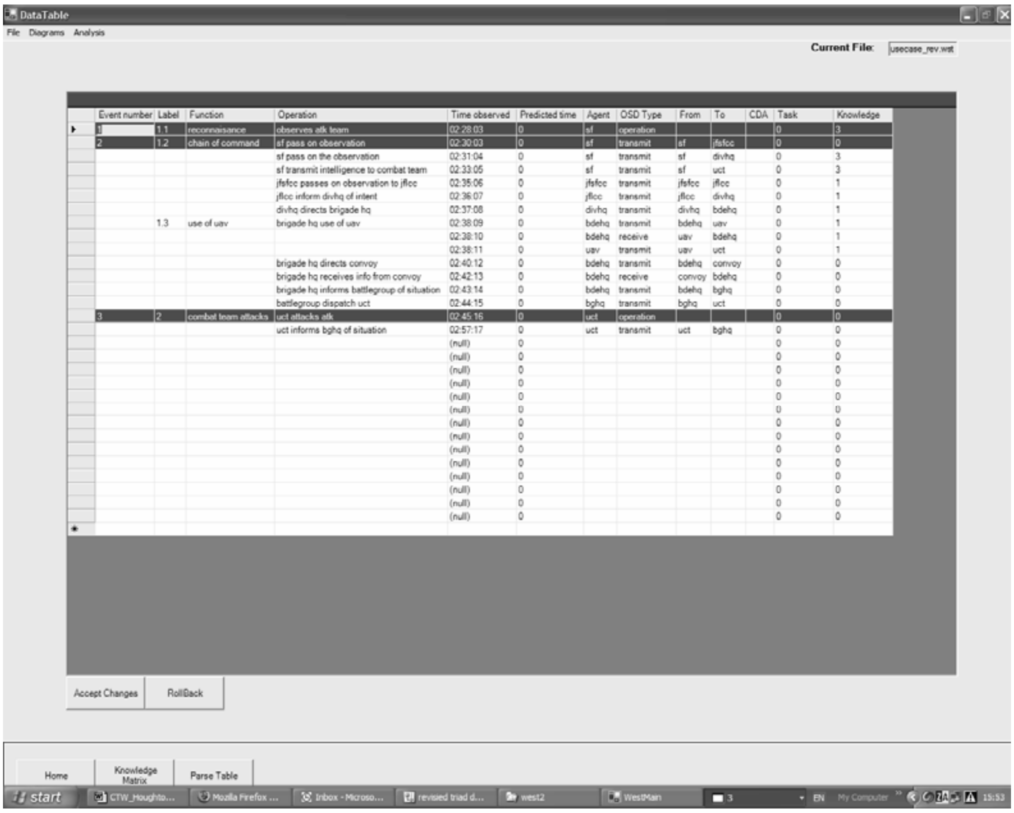
Figure 1. Relationship and mappings between task network, social network and propositional knowledge networks

This method of representation is consistent with claims that a networked force is not one that merely employs a physical communications network, but one whose whole operation should conceptually be understood in terms of the complex nature of relationships and dynamics that exist between entities (e.g., Atkinson & Moffat, 2005) Whilst WESTT is ostensibly a software tool, it should also be noted it implies (to some extent) a particular methodological approach to the study of team and C2 behavior and a particular theoretical stance on the nature of human-centered systems. An implication of this view is that changing an element of one network has repercussions in the other two networks. For example, adjusting manning to meet performance targets in the task network will have repercussions for both the social network within the team and for the distribution and flow of knowledge within the team, both of which will have further repercussions upon task performance itself. These changes may of course be either beneficial or harmful to overall performance. WESTT then allows analysts to investigate these complexities to prevent unforeseen damage occurring both in terms of the network topographies (e.g., creating bottlenecks in information flow) and in terms of metrics of predicted error, workload and task duration. More positively this approach also allows analysts to produce original and non-obvious solutions to problems (e.g., it is possible that what appears to be a manning problem may actually be a symptom of an underlying knowledge distribution problem that can be solved without changing the manning itself).

In the next section of this paper we will describe in some depth the various modules that make up the WESTT software package. In doing this we shall make reference to an example of how WESTT can be used to support a use-case investigation of a hypothetical military action described by Lloyd (2004). The scenario describes a brigade-level action in urban terrain in which Brigade HQ plays the central command and control role, both passing reconnaissance from Special Forces and a UAV (Unmanned Aerial Vehicle) down to the Urban Combat Team and also communicating with a convoy. We used WESTT to evaluate a change in network architecture suggested by Lloyd (2004) wherein rather than information being routed via Brigade HQ, a direct data-feed between the Urban Combat Team and the two reconnaissance assets (Special Forces and the UAV) is added, in line with NEC-style thinking about the provision of information directly to “on the ground” decision makers and effectors. WESTT allows rapid construction, assessment and modification of designs: the figures and data reported here took no longer than 20 minutes of keyboard time to produce, although it should be of course noted that the time spent to come to an understanding a scenario can clearly be highly variable depending on the expertise of the individual and the complexity of what is being studied. Where data required for a WESTT analysis were not present in the original text we have taken the liberty of inventing some points of data informed by the text, as we would expect an analyst to be able to employ their professional judgment about a situation.

The main data table

At the heart of WESTT, in terms of both the user interface and the underlying method of analysis is the data table. The data table, as the name implies, simply displays an ordered list of events over time together with the agents (human or technological) involved and relevant details (labels breaking the action down by phases and other descriptive material can be added for example). In essence the data table is very similar to a spreadsheet and has similar editing capabilities, indeed data can readily be imported to WESTT from Microsoft Excel. In addition to the familiar spreadsheet functions, one can also ask WESTT to check that all the observations in the table fall in chronological order to prevent errors in analysis. A screenshot of the main data table is shown in Figure 2.



Event number	Label	Function	Operation	Time observed	Predicted time	Agent	OSD Type	From	To	CDA	Task	Knowledge
1	1.1	reconnaisance	observes atk team	02:28:03	0	sf	operation				0	3
2	1.2	chain of command	sf pass on observation	02:30:03	0	sf	transmit	sf	jfsfcc		0	0
			sf pass on the observation	02:31:04	0	sf	transmit	sf	divhq		0	3
			sf transmit intelligence to combat team	02:33:05	0	sf	transmit	sf	uct		0	3
			jfsfcc passes on observation to jflcc	02:35:06	0	jfsfcc	transmit	jfsfcc	jflcc		0	1
			jflcc inform divhq of intent	02:36:07	0	jflcc	transmit	jflcc	divhq		0	1
			divhq directs brigade hq	02:37:08	0	divhq	transmit	divhq	bdehq		0	1
	1.3	use of uav	brigade hq use of uav	02:38:09	0	bdehq	transmit	bdehq	uav		0	1
				02:38:10	0	bdehq	receive	uav	bdehq		0	1
				02:38:11	0	uav	transmit	uav	uct		0	1
			brigade hq directs convoy	02:40:12	0	bdehq	transmit	bdehq	convoy		0	0
			brigade hq receives info from convoy	02:42:13	0	bdehq	receive	convoy	bdehq		0	0
			brigade hq informs battlegroup of situation	02:43:14	0	bdehq	transmit	bdehq	bghq		0	0
			battlegroup dispatch uct	02:44:15	0	bghq	transmit	bghq	uct		0	0
3	2	combat team attacks	uct attacks atk	02:45:16	0	uct	operation				0	0
			uct informs bghq of situation	02:57:17	0	uct	transmit	uct	bghq		0	0
				(null)	0						0	0
				(null)	0						0	0
				(null)	0						0	0
				(null)	0						0	0
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Figure 2. The WESTT data table

Representation of task structure: Operation sequence diagram and UML renderings

On the basis of the information in the main data table, WESTT will automatically draw and label an Operation Sequence Diagram (OSD). The OSD has been widespread in the ergonomics community since the 1950s and provides a means of representing the activity of agents within a system over the course of a mission as Meister (1985) pointed out, “The OSD can be drawn at a system or task level and it can be utilized at any time in the system development cycle provided the necessary information is available. It can aid the analyst in examining the behavioural implementation of design alternatives by permitting the comparison of actions involved in these design alternatives.” [p. 67]. However, the use of the OSD has hitherto been beset by problems in their creation “…the task of drawing a complex OSD can be extremely cumbersome and expensive.” (Meister, 1985, p. 68). Various attempts have been made to automate the drawing of OSDs (particularly during the 1980s), although there are few if any commercial products that are currently available to do this. WESTT therefore fills this gap (Figure 3).

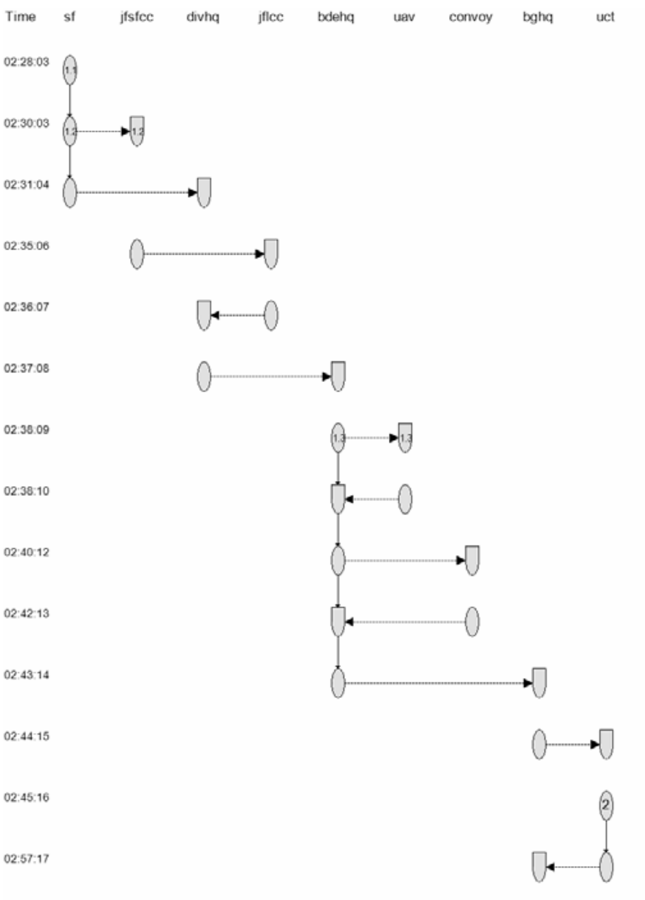


Figure 3. Operation Sequence Diagram for the Lloyd (2004) urban operations scenario.

In addition to the OSD, WESTT can also automatically generate Unified Modelling Language (UML) diagrams, namely, a Sequence diagram and a Use-case diagram). Whilst the OSD may be familiar to human factors and operational research experts, in engineering (and particularly software engineering) the UML system is popular and widely understood. Thus to make the tool useful to as wide an audience as possible and to facilitate communication between human factors analysts and engineers involved in the production of C2 technology we decided to add these UML options. The Sequence diagram (see Figure 4) is very similar to OSD in so far as it portrays much the same information (actions by agent over time) albeit using slightly different layout for its symbology. The Use case diagram displays the associations between individual actors and the tasks (termed use cases herein) that they are involved in. By offering a range of representations of the data we allow the analyst to pick the most relevant to their needs at the time. For example, if one is interested in which agents are collaborating on particular tasks but have no interest in the timings involved, the Use case diagram may be a more preferable rendering of the information then the OSD or the UML Sequence diagram.

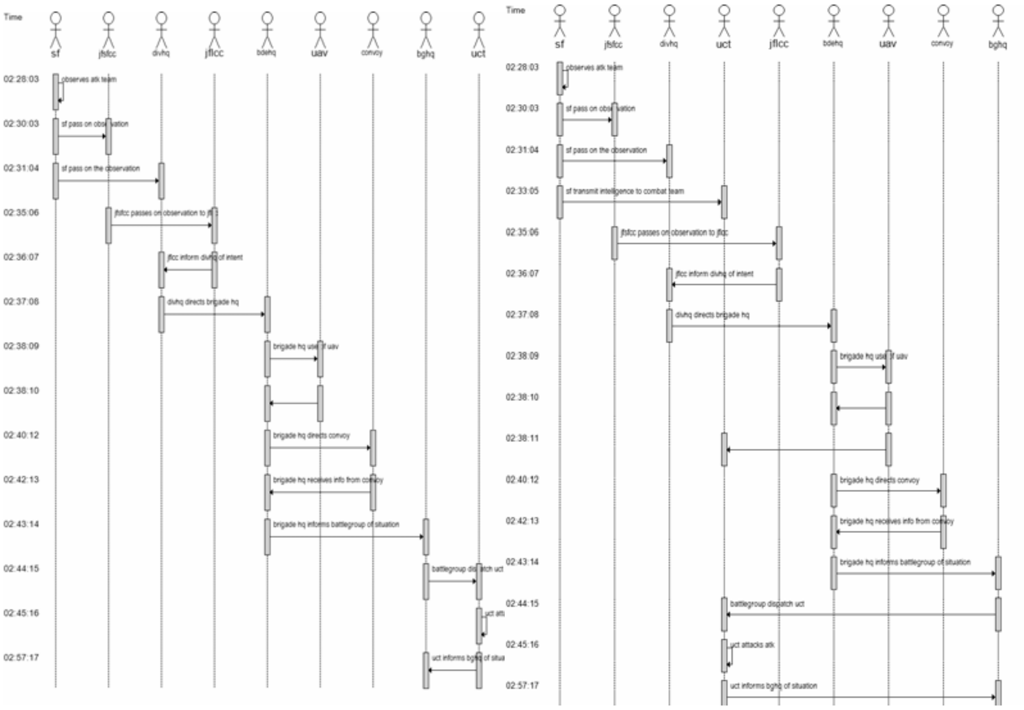


Figure 4. UML sequence diagrams. The left hand pane depicts a version of the scenario without linkages between Special Forces and UAV reconnaissance and the Urban Combat Team, the right-hand pane shows the scenario with those links, and the event that derive from them instantiated. Note that these differences are clearly apparent at a glance.

Social network analysis

Social network analysis is based on the simple intuition that the structure of relationships between actors plays a determinant role in the performance or action of that social network and the actors within it. It is worth noting from the outset that social network theory is based upon empiricism and mathematics (indeed, modern social network analysis techniques would not exist had Graph Theory not undergone rapid development as a mathematical field in the 1970s). Today, social network theory is widely used across myriad disciplines; it can be used as a tool to investigate organizations, decision making, the spread of information, the spread of disease, mental health support systems, anthropology, child development etc. Most recently there has been a great deal of enthusiasm for the using the techniques of social network analysis (SNA hereon) to study the internet and connections between both web pages (e.g., Google ‘page rank’ technology) and internet users (e.g., see Adamic, Buyukkoten & Adar, 2003). In terms of studying the architectures encountered in the increasingly complex Network Enabled command and control networks (both pre-designed and formed *ad hoc*) SNA would appear to be the logical choice of analysis tool. Modelling of military command and control networks using this general approach has already yielded intriguing results (e.g., Dekker, 2002).

Teamwork is therefore explored and quantified through methods of Social Network Analysis. On the basis of the central data table WESTT automatically extracts a Social Network diagram that graphically portrays the interconnections between agents within a system. Each agent is represented as a node and is connected to others via lines termed “edges”. Again, whilst there are products that will draw social networks, WESTT is notable for allowing one to go directly from empirical data to a full social network. Qualitative analysis of social networks can yield interesting results in and of itself; one can for example identify nodes that are acting as hubs that connect other nodes. In some cases this function may not have been deliberately assigned to an individual with implications for their performance in other tasks. In Figure 5 we see social network outputs that show, with regard to the urban operations tactical vignette discussed earlier, the change to the topography of the network extra reconnaissance to Urban Combat Team linkages provide.

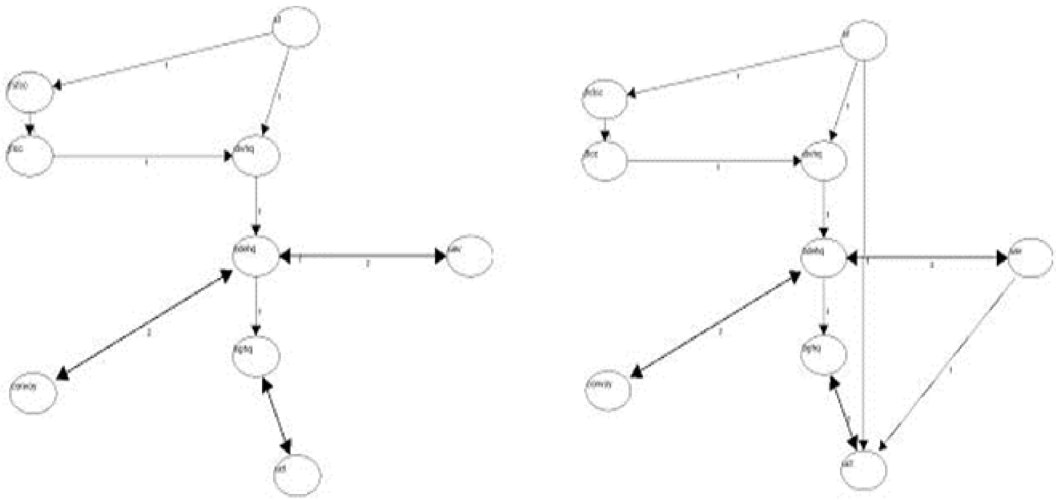


Figure 5. Social networks. The left-hand social network shows the number of communications between agents in terms of thickness of line. The right-hand social network adds linkages between reconnaissance assets and the Urban Combat Team. This notably introduces extra redundancies; even if something happens to Brigade HQ it is clear from the right-hand social network that vital reconnaissance data will be available to the Urban Combat Team and those who are linked to them. By contrast, in the left-hand social network we can see that there is relatively little redundancy; if something happens to Brigade HQ the network will be shattered in four isolated units.

As well as giving the analyst a visual representation of the relationships between agents, which can be used to understand the general character of the social network, the data on which it is based can be analyzed using algorithms and statistical techniques (for a comprehensive review see Wasserman & Faust, 1992). For our purposes these metrics fall into two main camps; measures of the activity of nodes and measures that pertain to the topography of the network. Each class of metric provides a different perspective on the structure and performance of the social network. A measure of node activity implemented in WESTT is Sociometric status, which gives an indication of the contribution a given node makes to the overall amount of communication in the network.

The other two social network metrics currently instantiated in WESTT are geodesic distance and centrality that relate more directly to the physical form of the network. Geodesic distance refers to the shortest possible path between two nodes in a network and thus can be assumed to be shortest path for a communication to pass between two agents. Typically, the greater the geodesic distance between two agents, the longer information will take to propagate from one to another and the greater the risk that information will lose its value both because of the degradation encountered in inaccurate reception or retransmission (as in a game of ‘Chinese whispers’) and in terms of the information pertaining to a rapidly changing situation being rendered inaccurate before it reaches its eventual recipient. If the information in question is intelligence this might mean plans are formed or orders issued that are inappropriate to the extant situation with the result that clumsy, uncoordinated or even hazardous actions are taken. Centrality is an overall indication of how close a node is in terms of geodesic distance from the other nodes in the network.

Measures of sociometric status and centrality for the two variations on the urban operations scenario are shown in Tables 1 and 2.

Table 1.

Without extra links

Agent	Sociometric status	Centrality
sf	6	4.526316
jfsfcc	6	3.583333
divhq	9	6.142857
jflcc	6	4.526316
bdehq	18	6.615385
uav	6	4.3
convoy	6	4.3
bghq	9	4.777778
uct	6	3.44

Table 2.

With extra links between reconnaissance assets and the Urban Combat Team.

Agent	Sociometric status	Centrality
sf	10.5	5.142857
jfsfcc	7	3.789474
divhq	10.5	5.538462
uct	14	4.8
jflcc	7	4
bdehq	21	5.538462

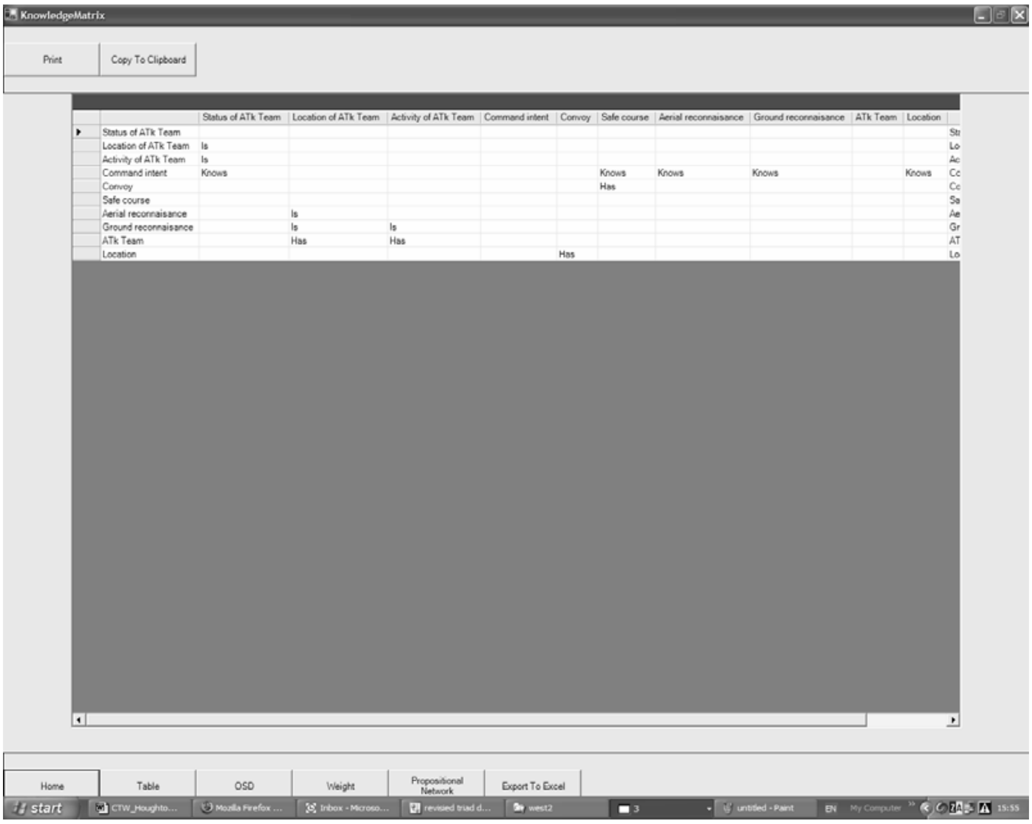
uav	10.5	4.5
convoy	7	3.6
bghq	10.5	4.5

Note for example that increased connectivity raises sociometric status for most nodes, but that the minor changes have adjusted the balance of power within the network; Special Forces assets are now increasingly influential and central within the network. This means that they now play a far more important role within the network but also that their loss or infiltration of their communications would have an increasingly profound impact upon the wellbeing of the mission.

Representing system knowledge structure: Propositional networks

In addition to importing and representing the observational data, WESTT supports the construction of what are termed Propositional Networks. The basic approach is for the analyst to collect information from debrief, interviews, procedure manuals and other sources, to define the ‘knowledge objects’ relevant to the mission. These knowledge objects are then connected by linkages based on semantic propositions that define their linkage (e.g., IS, HAS, KNOWS), thus a network of knowledge is produced (see for example, Anderson, 1983). In terms of constraining what a proposition can be we take Anderson’s approach that a proposition is a basic statement, “…the smallest unit about which it makes sense to make the judgment true or false” (Anderson, 1980, p.102). To-date we have found the best way to elicit knowledge objects has been to use the Critical Decision method for structuring interviews. The Critical Decision method (Klein, 1989) is a form of critical incident technique. According to Klein (1989), “The CDM is a retrospective interview strategy that applies a set of cognitive probes to actual non-routine incidents that required expert judgment or decision making” (p. 464). In our implementation of this approach, the interview proceeds through a series of four stages: briefing and initial recall of incidents; identifying decision points in specific incident; probing the decision points; and finally checking.

In terms of WESTT itself, the knowledge objects are entered into a matrix which allows the analyst to define the relationship between the objects (see Figure 6).



	Status of ATk Team	Location of ATk Team	Activity of ATk Team	Command intent	Convoy	Safe course	Aerial reconnaisance	Ground reconnaisance	ATk Team	Location	
Status of ATk Team											St
Location of ATk Team	Is										Lo
Activity of ATk Team	Is										Ac
Command intent	Knows					Knows	Knows	Knows		Knows	Cc
Convoy						Has					Cc
Safe course											Sa
Aerial reconnaisance		Is									Ae
Ground reconnaisance		Is	Is								Gr
ATk Team		Has	Has								AT
Location					Has						Lo

Figure 6 Knowledge object matrix with propositions

WESTT is then able to automatically provide a graphical representation of the ‘space’ of knowledge objects that are involved in the mission (Figure 8). Typically, this network is then presented to Subject Matter Experts (SME) in order to validate the level of detail and the inclusion of specific knowledge objects. Once the network has reached an acceptable state, it can be subjected to network analysis in a similar way to the Social Networks to identify trends in the relationships between information. It is this network of propositions that embodies the novel conceptualization of Situation Awareness used by WESTT. Rather than focusing on aspects of ‘awareness’, we are more concerned with defining the ‘situation’. In this work, we view the situation as comprising a collection of objects about which the agents within the system require some knowledge in order to operate effectively. Nodes in a PN can be easily associated with specific agents through color coding. This provides an intuitive representation of ‘who knows what’ during the phases of an incident, which can be useful for considering gaps in awareness, requirements for shared knowledge or potential for conflicting interpretations of the same knowledge. WESTT provides a facility to “play back” the spread of activation in the propositional network so the analyst can watch the spread of knowledge use and sharing over the duration of the scenario.

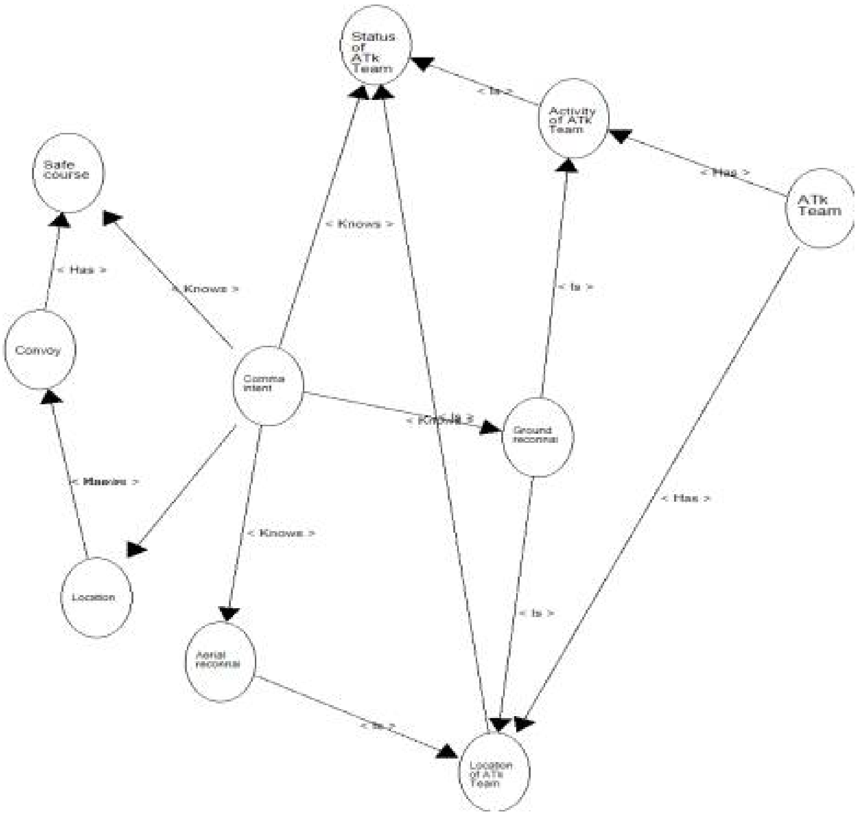


Figure 7. Estimated propositional network for an urban operations scenario. In terms of the NEC-related changes that might be made to the social network and the task, we can see these have little impact upon the structure of the propositional network, but do affect who shares different knowledge objects and at what point in time they are shared. That the items are shared suggests we may have some confidence that a consistent operational picture is held across the team.

Workload, Error and Time metrics.

The final part of WESTT is the calculation of workload, error and time metrics. In many forms of Human Reliability Analysis (HRA), an approach is taken that is analogous to Failure Mode Effect Consequence Analysis (FMECA). This is a standard engineering approach that defines failure modes for specific elements of a problem. In HRA approaches, an element might be a task and a failure mode might be “done too early/too late”. WESTT uses this notion for its initial (analyst driven) inspection of operations. Each operation can, from a pop-up menu be assigned one or more specific failure modes. The resulting table this produces shows operation by failure mode.

Given that each operation is made up of specific tasks, the assignment of time to tasks in simply a matter to looking values up in a database. These times are collected from the literature and represent unit-times for specific tasks. WESTT can combine these times into a simple linear model of performance, i.e., by summing all the times in manner that is similar to keystroke level models (e.g., Card, Moran & Newell, 1983). As an alternative we are currently implementing an method of extending this analysis into a critical path model (e.g., Gray, John & Atwood, 1993; Baber & Mellor, 2001) which can better account for the parallelism of human activity. Essentially the critical path technique is about identifying which activities may safely occur in parallel, which tasks are dependent on the completion of other tasks before they commence and thus ultimately which tasks are critical to maintaining a schedule and which are not.

The study of Human Factors has developed a range of measures to describe how busy a person is in terms of how much cognitive and physical activity they are required to perform. In terms of predictive analysis of workload, the general approach would appear to follow the notion that changes in activity can be mapped over time to provide an index of loading (Parks & Boucek, 1989); this could be considered as a function task scheduling (Moray, Dessousky, Kijowski & Adapathya, 1991) or in terms of competition between cognitive resources (North & Riley, 1989). At present WESTT provides a simple metric for workload based on the operations performed by a given agent during a defined phase of the mission. This is derived from the OSD and provides an index of 'operations demand'. However, workload is also a cognitive function and subsequent developments of the workload algorithms in WESTT will take into account the number and complexity of knowledge objects (as represented in the Propositional Network) to provide a scaling factor for the operations demand. In our analysis of the urban operations vignette where additional links between reconnaissance assets and the Urban Combat Team were implemented, we found that because information is duplicated there is no extra time cost associated with its production, but that workload increases for the Urban Combat Team, as they are now provided with extra communications events (between themselves and the reconnaissance assets) rather than a single communications event between themselves and Brigade HQ.

Discussion

This paper has described the rationale behind and use of the WESTT software tool. It is envisaged that WESTT will provide a novel and useful means of representing team activity, and will be particularly beneficial for exploring future configurations in command and control system structure. By supporting analysis at several levels, it is possible to explore the effects of changes to system structure, the introduction or removal of knowledge objects (which might be operating procedures, cultural expectations or tactical information) or the replacement of human agents with technology, on operational effectiveness and system performance. Through the convergence of measures and modes of data representation in WESTT, an analysis using the software can be used to indicate barriers to team activity such as deficits and asymmetries in expertise and situational awareness, pinch-points and sub-optimal social and communication network configurations.

Because these analyses and metrics are largely automated WESTT can be used as an analytical prototyping tool allowing one to rapidly compare different approaches by manipulating data in the main data-table. By supporting analysis at several levels, it is possible to explore the effects of changes in system structure, the introduction or removal of knowledge objects (which might be operating procedures, cultural knowledge or tactical information) and the replacement or augmentation of human agents with technology. One way of understanding how the various networks are linked is to consider that within WESTT, for each agent (that is, a human or technological entity) we have the following information available: what they have done or are doing (operation sequence diagram); what they know (knowledge objects embedded in a propositional network); what their modes of failure might be at various points (error) and how they spend on task (time/workload). To answer a design question using WESTT we might want to select from a subset of these attributes from a subset of agents. Alternatively we may survey the overall structures of knowledge, social nets and tasks to gain an appreciation of the functioning of the system as an entity in itself.

As an integrative tool, many individual aspects of WESTT have already been subject to extensive testing, academic discussion and validation. For example, there is a large literature discussing the uses of social network modeling (e.g., Wasserman & Faust, 1992) and much of the workload, error and time metrics are in common use by Human Factors practitioners. The use of “plug in” databases of task time and error also allow one to employ pre-validated and reliability-tested estimates.

Validation of WESTT as a whole has so far consisted of discussions with Subject Matter Experts regarding the face validity of the outputs and usefulness of comparing different types of representations as an aid to the investigation by analysts of complex datasets (this has taken place with regard to Police, Fire and power industry scenarios). In addition to this we are currently following two more formal approaches to validation. First, we are comparing WESTT predictions with outcomes delivered by simulation tools (such as MicroSAINT). Second, and perhaps more importantly given an analysis tool’s ultimate duty is to produce metrics and data that accord with reality itself, we are involved in ongoing experimental work looking at the effects of different network structures and technologies upon the activities of teams of human participants in different games and scenarios and comparing the outputs of WESTT analyses against those real world patterns of performance.

Future directions for the development of WESTT include adding more metrics as appropriate and in particular “headline figures” which more succinctly describe the performance of the system as a whole.

Acknowledgements. This work from the Human Factors Integration Defence Technology Centre was part-funded by the Human Sciences Domain of the UK Ministry of Defence Scientific Research Programme. The WESTT software package is available on request via our website: http://www.hfidtc.com

References

Anderson, J. (1983). *The architecture of cognition*. Cambridge, MA: Harvard University Press.

Adamic, L. A., Buyukkoten, O., & Adar, E. (2003). A social network caught in the web. *Internal report, HP and Google Labs.*

Atkinson, S. R. & Moffat, J. (2005). The agile organization: From informal networks to complex effects and agility. *Washington DC: DODCCRP Publications.*

Baber, C. & Mellor, B.A. (2001). Modelling multimodal human-computer interaction using critical path analysis, *International Journal of Human Computer Studies ,54*, 613-636.

Baber, C. and Stanton, N. (2001). Analytical prototyping of personal technologies: using predictions of time and error to evaluate user interfaces, In M. Hirose (ed) *Interact'01*, Amsterdam: IOS Press, 585-592.

Baber, C. and Stanton, N. (1999). Analytical prototyping. In J.M. Noyes and M. Cook (eds.) *Interface Technology*, Baldock: Research Studies Press. 175-194.

Card, S.K., Moran, T.P. and Newell, A. (1983). *The Psychology of Human-Computer Interaction*, Hillsdale, N.J.: LEA.

Dekker, A.H. (2002). C4ISR Architectures, Social Network Analysis and the FINC Methodology: An Experiment in Military Organisational Structure. *DSTO report DSTO-GD-0313*.

Gray, W.D., John, B.E. and Atwood, M.E. (1993). Project ERNESTINE: validating a GOMS analysis for predicting and explaining real-world performance, 237-309. *Human-Computer Interaction, 8*

Houghton, R. J., and Baber, C. (2005). Social aspects of Network Enabled Capability: Information sharing and decision-making. *IEE People and Systems conference: Who are we designing for?* London, UK, November 2005.

Kirwan, B. (1994). *A guide to practical Human Reliability Assessment*. London: Taylor & Francis.

Klein, G.A. (1989) Recognition-Primed Decisions, In W.B. Rouse (ed) *Advances In Man-Machine Systems Research Volume 5*, Greenwich, CT: JAI, 47-92,

Lloyd, M. (2004). The NEC Use-Case Methodology. *Distillation, 8*, 16-23.

Moray, N., Dessousky, M.I., Kijowski, B.A. and Adapathya, R. (1991) Strategic behaviour, workload and performance in task scheduling, *Human Factors*, 33 607-629,

Meister, D. (1985) *Behavioral Analysis and Measurement Methods*, New York: Wiley.

Ministry of Defence (2004). Network enabled capability, an introduction. *Ministry of Defence, UK.*

Ministry of Defence (2005). *Network enabled capability*. Joint Services Publication 777, London.

North, R.A. and Riley, V.A. (1989) A predictive model of operator workload, In G.R. MacMillan,D. Beevis, E. Salas, M.H. Strub, R. Sutton and L. van Breda (eds) *Applications of Human Performance Models to System Design*, New York: Plenum, 81-90, Parks, D.L. and Boucek, G.P. (1989) Workload prediction, diagnosis and continuing challenges, In G.R. MacMillan, D. Beevis, E. Salas, M.H. Strub, R. Sutton and L. van Breda (eds) *Applications of Human Performance Models to System Design*, New York: Plenum, 47-64.

Wasserman and Faust (1992). *Social Network Analysis: Methods and Applications*. Cambridge, U.K. Cambridge University Press.