Paper Submission for:

10th International Command and Control Research and Technology Symposium:

The Future of Command and Control

TITLE OF PAPER:

WESTT (Workload, Error, Situational Awareness, Time and Teamwork): An analytical prototyping software tool for C2

Name of Author/Co-Authors(s):
Robert J. Houghton[1], Chris Baber[1] and Mal Cowton[2]

Point of Contact:
Robert J. Houghton

Organisation:
Human Factors Integration Defence Technology Centre, UK.
[1] The University of Birmingham, Birmingham UK.
[2] Aerosystems International, Yeovil, UK.

Complete Address:
Electronic, Electrical & Computer Engineering
School of Engineering
The University of Birmingham
Birmingham, B15 2TT
United Kingdom

Telephone/Fax Numbers:
Tel: +44 (0)121 414 42934
Fax.: +44 (0)121 414 4291

E-mail Address:
R.J.Houghton@bham.ac.uk

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.

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WESTT (Workload, Error, Situational Awareness, Time and Teamwork): An analytical prototyping software tool for C2

Robert J. Houghton[1], Chris Baber[1] and Mal Cowton[2]
[1]HFIDTC/The University of Birmingham, UK
[2]HFIDTC/Aerosystems International, Yeovil, UK

Abstract

In order to explore the potential impact of novel command and control configurations, it is useful to have some means of extrapolating from existing systems and comparing the outcome of change from existing to novel systems. By taking a 'systems' view of operations, it is possible to consider the impact of reconfiguration upon the performance of the system and upon the agents operating within the system. The aim of the WESTT analytical prototyping tool is to support systems analysis and to allow the analyst to explore the impact of reconfiguration through the manipulation of models. In this paper we describe the underlying approach behind the tool which emphasises taking multiple perspectives (task/social network/knowledge network) with regard to the activity being analysed and we describe the functionality of the present version of the software.

Introduction.

The WESTT (Workload, Error, Situational Awareness, Time and Teamwork) software tool is currently undergoing iterative development by the Human Factors Integration Defence Technology Centre, UK (HFIDTC). The motivation for the development of the tool was to produce a means of visualising, measuring and modelling C2 and team activity. WESTT represents team activity at a systems level in which both humans (and the technologies they interact with) are represented as agents. Representing humans and technology at an equal level is integral to understanding their relationship and also allows one to directly model the impact of augmenting or even replacing team members with new technology. In addition to its role in processing empirical data, WESTT provides a means of evaluating systems-level descriptions of operations with a view to supporting analytical prototyping. Analytical prototyping is based on the concept that initial system descriptions can be quantitatively explored in order to evaluate the potential benefits of modification (Baber and Stanton 1999, 2001). In other words, a prototyping approach to design can be taken in which an initial system specification - perhaps based on observations of current operations - can be quantified and then modified; then with each iteration of the process, the resulting system can be quantified and compared with the initial description in order to evaluate the scale of likely improvements. In summary WESTT has a range of possible applications:

- Analysis of field data and evaluation of current practice
- Comparison between actual performance and the design/doctrine
- Evaluation of changes to current practice through modelling
- Evaluation of performance in training and virtual environments

It is important to note that WESTT does not in its current form offer the means to produce full-blown simulations of the battlefield but rather is an accessible tool for rapid prototyping and assessment in the hands of an analyst who may use it together with their expertise, existing simulation tools and data. The analyses offered by WESTT may give strong indications about the implications of certain patterns of activity but the tool does not in itself generate statements about how these problems might be rectified or speak directly to issues of operational effectiveness. Instead, WESTT allows the analyst to quickly evaluate different approaches and candidate solutions with a view to the predicted risks of error, time delay, workload, inappropriate social network configuration and the distribution of knowledge in the system as a whole.

Underlying approach and overview.

Key to the design of WESTT is the contention that, with the advent of network-enabled systems and the increased recognition of the importance of knowledge management to war fighting, fully understanding C2 performance requires an appreciation of what happened in a given situation (or what is predicted might happen) 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 is best understood as being the product of a ‘network of networks’ wherein the examination of one network requires knowledge of the structure of the others (all working within a technologically constrained network). This interrelation is depicted in Figure 1. 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 behaviour.

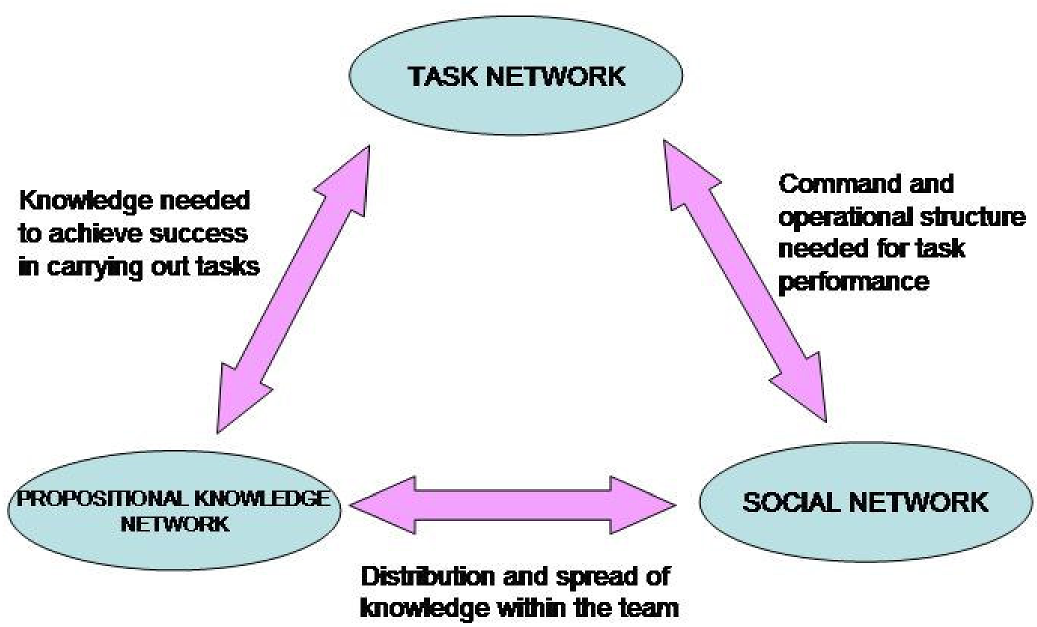


Figure 1. Relationship and mappings between task network, social network and propositional knowledge network to form a “network of networks”.

An implication of this view is that changing an element of one network has repercussions within 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 around 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 (e.g., creating bottlenecks in information flow) and also to help an analyst envisage and test original 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).

Our approach has been formed with primary regard to military operations, but we believe the WESTT tool can be used widely in the study of any organisation where C2 and team performance are important. Indeed, the screenshots in the present paper are of emergency service (Police and Fire) operations we have already analysed using the tool (e.g., Stanton et al., 2005).

CASA.

The C4I Activity Sampling Application (CASA) is a companion application to WESTT designed to support the collection of field observation data. The software currently runs on Personal Digital Assistants (PDAs) like the iPAQ and on portable tablet computers for easy deployment in the field. As we will see shortly, WESTT by default represents team activity using a comprehensive taxonomy of actions the same as those found in Operation Sequence Diagrams; these include Transmit, Receive, Inspect, Operate, Decide and Store. On observing a given action the analyst need only click on the screen to identify the actor and click to identify the action. These data are then time stamped and saved. If the analyst selects Transmit or Receive, a further screen is displayed to allow selection of the medium being used, i.e., Visual, Electrical, Sound / Verbal, Internal Communication, External Communication, Touch, Mechanical, Walking, and Hand delivered. After defining the medium of communication the analyst then specifies the agents sending and receiving the communication. On completing the observation, the analyst then is taken to an ‘overview’ screen. This shows the details of the observation (entered on the initial screen) together with a scrolling window showing previous observations. The presentation of the observations in this format allows initial review of the data. Upon returning from the field, the analyst can simply transfer the comma-separated data directly into WESTT or else combine/edit observations in a spreadsheet for subsequent export to WESTT. Three screens from the CASA user interface are depicted in Figure 2.

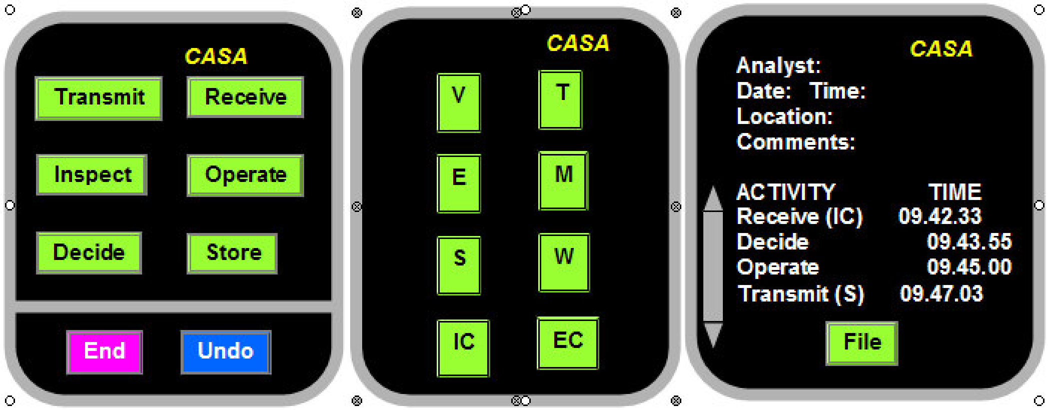


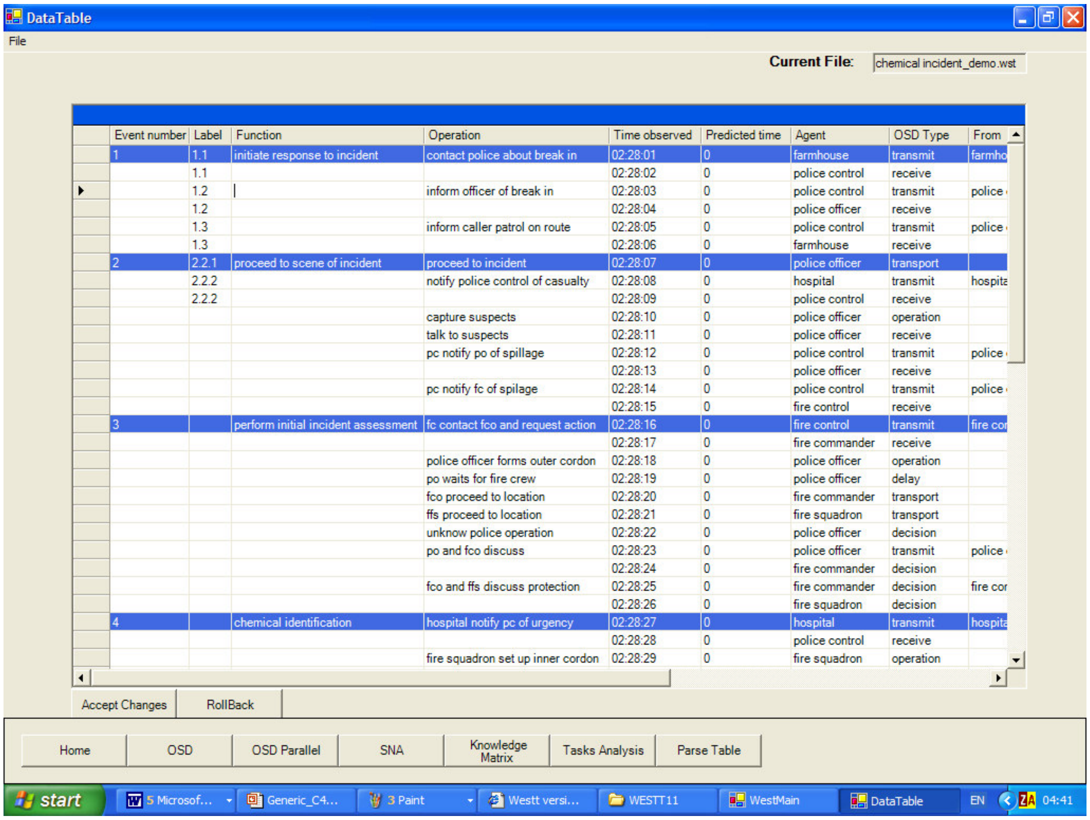
Figure 2. CASA interface screens

Whilst CASA has been produced to reduce the difficulty of field observations, it should also be noted that one might instead choose to use pen and paper in the field and simply transcribe the results into a suitable spreadsheet back at base. One might also use official documents to produce a representation of "model" performance. We have also had success utilising official event logs in studies of Police operations and envisage it might also be possible to use data feeds from simulators, virtual environments and network-enabled systems themselves.

Main data table.

At the heart of WESTT, in terms of both the user interface and the underlying method of analysis is the main data table (see Figure 2 which depicts the architecture of the system). The data table, as the name implies, simply displays an ordered list of events over time together with the actors involved and other relevant details (labels breaking the action down by phase 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; in addition 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 3.

It is through the manipulation of this data-table that the analyst can try out different approaches. For example, a team of Firemen may have been recorded putting out a blaze. The analyst may wish to investigate how adding an extra level of command might have affected events in response to workload problems reported by Fire commanders (e.g., adding an extra agent into the scenario and transferring some command activities and decisions to them). It may be the case that this solution works and reduces the workload but alternatively modelling of the time taken to pass communications and make decisions along the chain of command may reveal this is inadvisable if the observed timeframe for events is to be met. Alternatively one might want to remove a Fireman from the team and see if the remaining work can be split up amongst those that remain without any individual being overburdened. It might quickly be observed somebody needs to be in two places at one time or perhaps it would require one Fireman to be skilled in two very different areas of expertise. He may even be called upon to have knowledge of ongoing events he has no way of knowing about. Such things may be far from obvious in a complex scenario and WESTT is an attempt to aid analysts in dealing with the high levels of complexity distributed team performance in NEC-enabled contexts can produce. Rather than computing optimal solutions to problems itself, the tool encourages a different sort of process, namely analytical prototyping, wherein the analyst can rapidly try out of ‘what if’ scenarios and “tweak” the design with feedback in the form of ongoing automatic analyses of the implications of those changes.



Event number	Label	Function	Operation	Time observed	Predicted time	Agent	OSD Type	From
1	1.1	initiate response to incident	contact police about break in	02:28:01	0	farmhouse	transmit	farmho
	1.1			02:28:02	0	police control	receive	
	1.2		inform officer of break in	02:28:03	0	police control	transmit	police
	1.2			02:28:04	0	police officer	receive	
	1.3		inform caller patrol on route	02:28:05	0	police control	transmit	police
	1.3			02:28:06	0	farmhouse	receive	
2	2.2.1	proceed to scene of incident	proceed to incident	02:28:07	0	police officer	transport	
	2.2.2		notify police control of casualty	02:28:08	0	hospital	transmit	hospita
	2.2.2			02:28:09	0	police control	receive	
			capture suspects	02:28:10	0	police officer	operation	
			talk to suspects	02:28:11	0	police officer	receive	
			pc notify po of spillage	02:28:12	0	police control	transmit	police
				02:28:13	0	police officer	receive	
			pc notify fc of spilage	02:28:14	0	police control	transmit	police
				02:28:15	0	fire control	receive	
3		perform initial incident assessment	fc contact fco and request action	02:28:16	0	fire control	transmit	fire cor
				02:28:17	0	fire commander	receive	
			police officer forms outer cordon	02:28:18	0	police officer	operation	
			po waits for fire crew	02:28:19	0	police officer	delay	
			fco proceed to location	02:28:20	0	fire commander	transport	
			ffs proceed to location	02:28:21	0	fire squadron	transport	
			unknow police operation	02:28:22	0	police officer	decision	
			po and fco discuss	02:28:23	0	police officer	transmit	police
				02:28:24	0	fire commander	decision	
			fco and ffs discuss protection	02:28:25	0	fire commander	decision	fire cor
				02:28:26	0	fire squadron	decision	
4		chemical identification	hospital notify pc of urgency	02:28:27	0	hospital	transmit	hospita
				02:28:28	0	police control	receive	
			fire squadron set up inner cordon	02:28:29	0	fire squadron	operation	

Figure 3. The main data table.

Operation sequence diagram / UML.

On the basis of the information in the main data table, WESTT will automatically draw and label an Operation Sequence Diagram (OSD). The use of the OSD has been widespread within 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 OSDs 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 4).

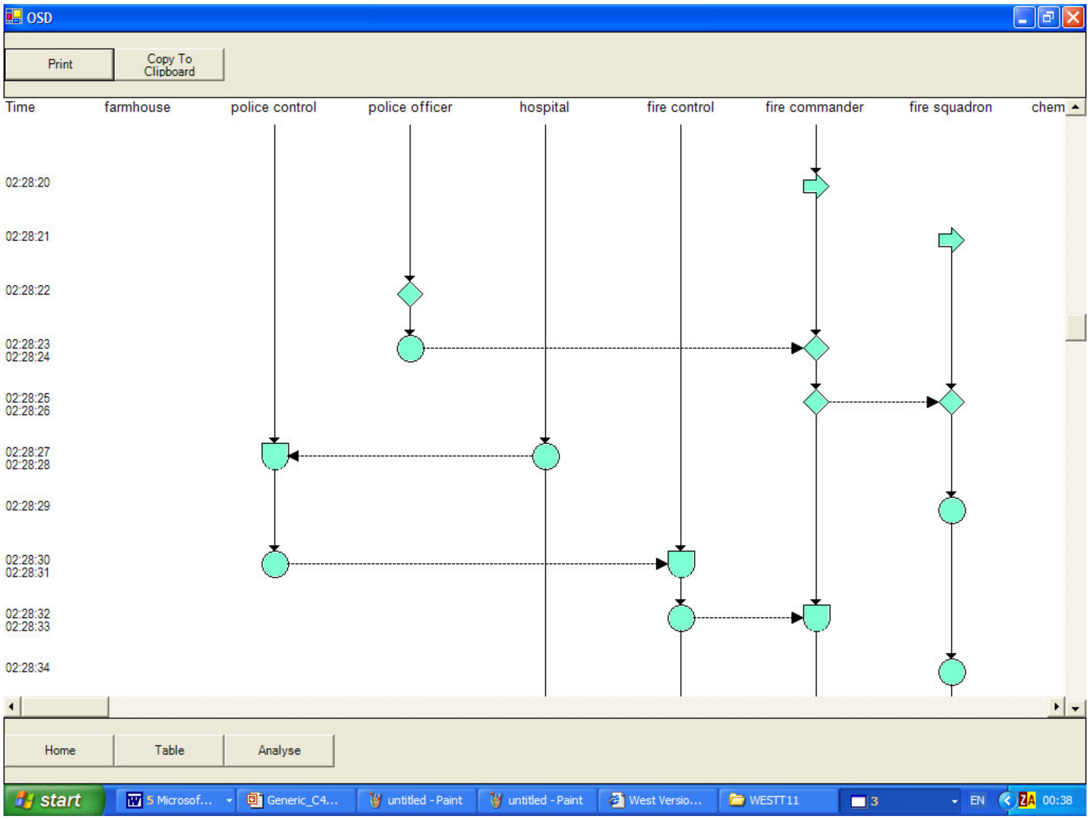


Figure 4. Operation Sequence Diagram

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 Operations Research experts, in Engineering (and particularly Software Engineering) the UML system is both 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 5a) is very similar to OSD in so far as it portrays much the same information (actions by agent over time) albeit using a slightly different layout and symbology. The Use Case diagram displays the associations between individual actors and the tasks (termed Use Cases herein) that they are involved in (see Figure 5b). 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.

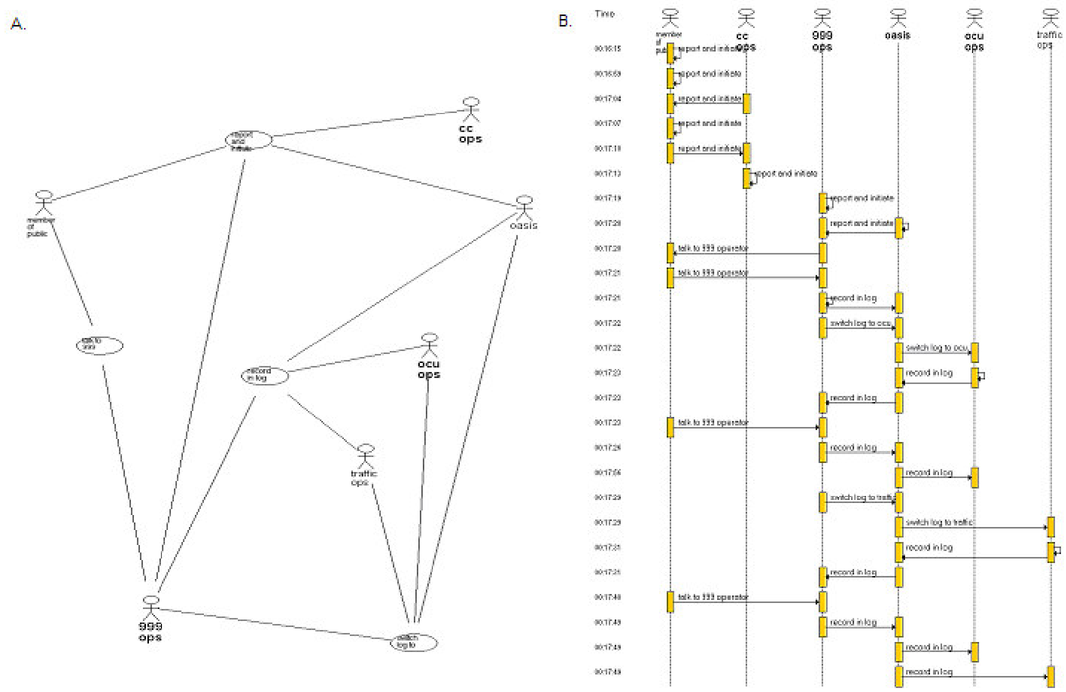


Figure 5. (a) UML use case diagram (b) UML Sequence diagram respectively

Social Network.

Teamwork is explored through concepts from Social Network Analysis. On the basis of the central data table (i.e., the same data used to generate the OSD and UML views) WESTT also automatically draws 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” (see Figure 6). 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 in one step together with the OSD as a representation of the context from which the social network arises (it is axiomatic within the social network analysis community that interpretations of social networks are only valid with careful reference to the situations that produce them). 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. Whilst we often envisage activity in teams as occurring with regard to specific hierarchies and protocols, upon observation it can often be seen simply from looking at a social network diagram that the reality is somewhat different.

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 organisations, 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 appears therefore 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).

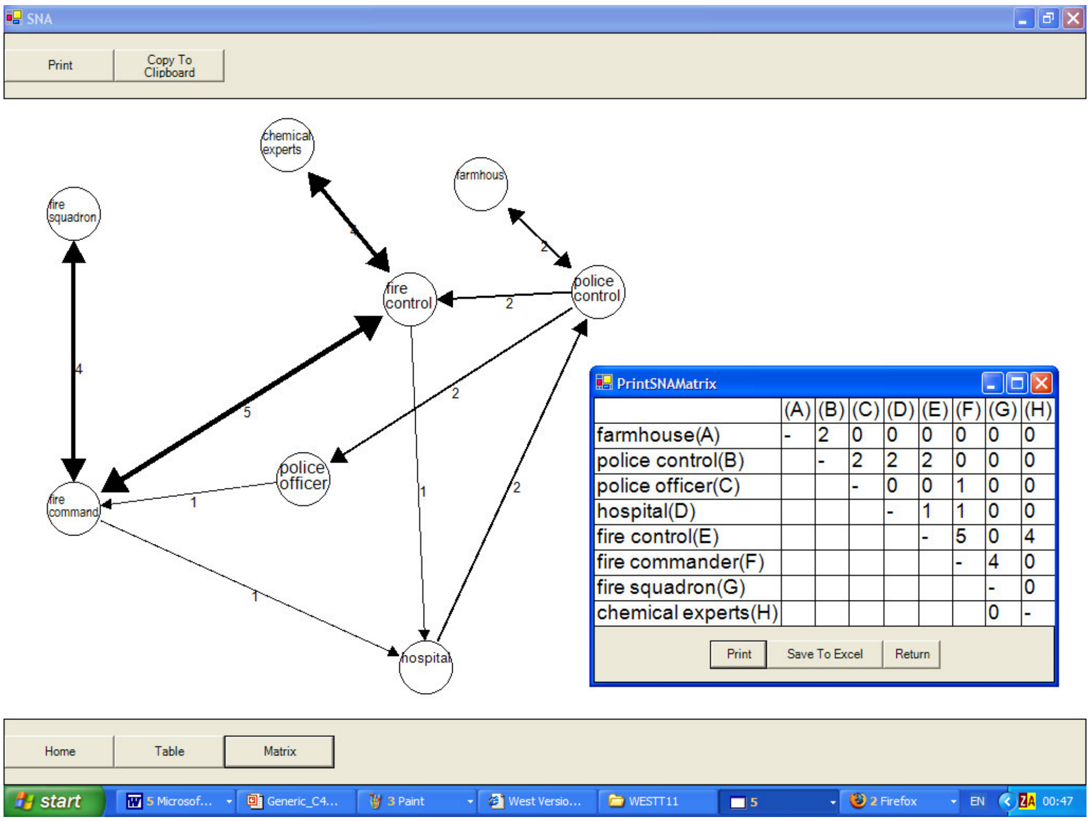


Figure 6. Social Network diagram and Social network matrix

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 analysed 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 which relate more directly to the 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 all the other nodes in the network.

Knowledge objects and the propositional network.

It is the network of propositions that embodies a novel conceptualisation of situation awareness at a distributed level used by WESTT. The notion of shared awareness, understanding and knowledge is an important part of the NEC/NCW vision as it contributes critically to the eventual aim of units being coordinated and synchronised at a high tempo on the battlefield (e.g., Alberts, Garstka, & Stein, 2003; MoD, 2004). Given the importance of information sharing and knowledge management to the contemporary analysis of C2 and the fact that our approach is somewhat unusual, we shall spend some time discussing in depth how it works and the process by which we arrived at our view. The question of how to usefully represent systemic understanding, awareness and coordination is a complex one and no doubt there are many possibilities that can be investigated with relevance to different requirements and levels of analysis. Our chosen approach for WESTT has been to use propositional networks of knowledge in a manner inspired by theories of distributed cognition.

Distributed cognition is an umbrella term used to describe a perspective that views system performance as a cognitive activity shared across individuals, their technology, artifacts and the environments in which all these things are found. Whilst it is perhaps most common to view cognitive activities as things that occur in the minds of individuals (or perhaps within machines that embody some degree of artificial intelligence), proponents of distributed cognition claim that cognitive activities (that is, the creation, transmission, processing, representation and re-representation of information to meet a goal) can all can identified within distributed systems that are made up of multiple actors and can in some cases be directly observed by a third party (see Hutchins, 1995a).

A cognitive system moves towards its goal-state by performing transformations upon representations and this is true of individual cognition and distributed cognition (Perry, 2003). Within a distributed cognitive system, transformations of representations are achieved by the combination, interpretation and re-presentation of information provided by the artifacts and individuals in the system (Hutchins, 1995a; Artman and Garbis, 1998). Artifacts are objects (and for want of a better word, "things") in the environment that permit a cognitive activity (e.g., pen and paper constitute a very common artifact that can transcribe and then hold information in an accessible form that can be accessed by another actor). Furthermore, distributed cognition assumes that, in some circumstances, actions performed by individuals can lead to information processing *directly at the systems level*, that is, without first requiring individual-level information processing. A trivial example of this would be that one can deliver a letter, thus transmitting and sharing information, without actually reading the letter itself. Alternatively a person might walk through a muddy field leaving a set of footprints. The individual might not after the event have a detailed recollection of their course or perhaps may have been wandering aimlessly in a daydream, but the information is there to be found in the environment. In short, the very act of manipulating an object in, or interacting with, the world can be sufficient to lead to the consequences of information-processing with or without an actor directly contemplating or processing the information.

A classic exposition of the principles of distributed cognition has been given in a description of the way in which an aircraft cockpit 'remembers' the speed of the aircraft (Hutchins, 1995b). The paper provides an account of the system interactions that occur in order to answer the apparently simple question of how fast an aircraft is flying. In the paper, Hutchins (1995b) assumes that systems have goals; in an aircraft system, the goal is to successfully complete the flight and a subgoal within this is achieving an appropriate flight speed. Components within this system might share a goal, and can perform actions to achieve sub goals in pursuit of the overall goal, but there is no one component that can directly claim to have completely met the goal in isolation, it is a combination of the different parts of the aircraft and the pilot. It is important to note then that studying a distributed system from a distributed cognition perspective is not about summating studies of individual knowledge or awareness; rather it is about describing the system as a whole. The properties a system might have overall may not necessarily be found through individual examination of its constituent parts; in other words distributed cognition is an emergent property of a distributed cognitive system. In prospect then, just as individual behavior can be understood with reference to theories of human cognition, so the behavior of distributed systems can be understood with reference to notions of distributed cognition, with, at face value at least, obvious appeal for those interested in understanding the way in which Network-Enabled socio-technical distributed systems may behave.

One difficulty in utilizing the theory of distributed cognition in a practical way is that its authors have generally taken an ethnographic/reportage approach, writing descriptions of activities they have observed and discussing how these might be interpreted as cognition. This would clearly be of little use within a rapid prototyping tool such as WESTT, thus we have attempted to operationalise some useful aspects of the distributed cognition perspective. For the purposes of the present work then, a key challenge was to find a way of illustrating what information is being represented within the system, and to show which agents have access to different aspects of the represented information at different times. In other words, our purpose is to identify solely the information used; we leave the question of how to describe changing representations within the system to later work. Following the assumption that a distributed cognition system embodies the same cognitive processes as an individual might (albeit spread across a system), we suggest that a means of describing knowledge in individuals, namely propositional networks, can be profitably applied to the representation of the action of and within a larger socio-technical system.

The basic approach is for the analyst to collect information from debrief, interviews, procedural 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 relationship (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 "…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 incidents; probing the decision points; and finally checking. The knowledge objects themselves take myriad forms; because they define the tasks and the knowledge needed to successfully complete them they include information about the scenario, pre-existing knowledge and skills actors must have (SOPs, cultural knowledge, doctrinal knowledge etc) and information that must be found in the scenario or environment to successfully complete a task. In many cases this would also likely include knowing about what other members of a team are doing although not necessarily the sharing of information directly between actors.

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 7). WESTT is then able to automatically provide a graphical representation of the 'knowledge space' involved in the scenario (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 social networks to identify trends in the relationships between knowledge objects. Nodes in a PN can be associated with specific agents through a system of colour coding (as can be seen in Figure 8) and also WESTT provides a facility to "play back" the spread of activation in the propositional network over time so the analyst can watch the spread of knowledge use and sharing over the duration of the scenario.

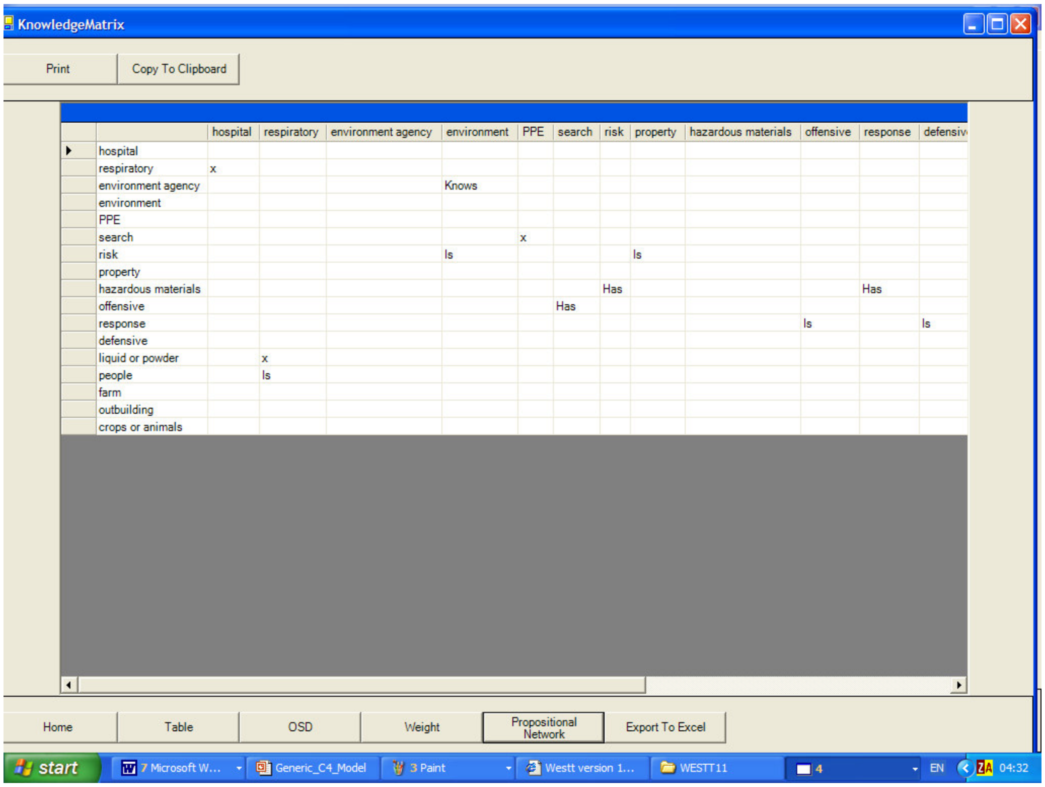


Figure 7. Knowledge object matrix with propositions

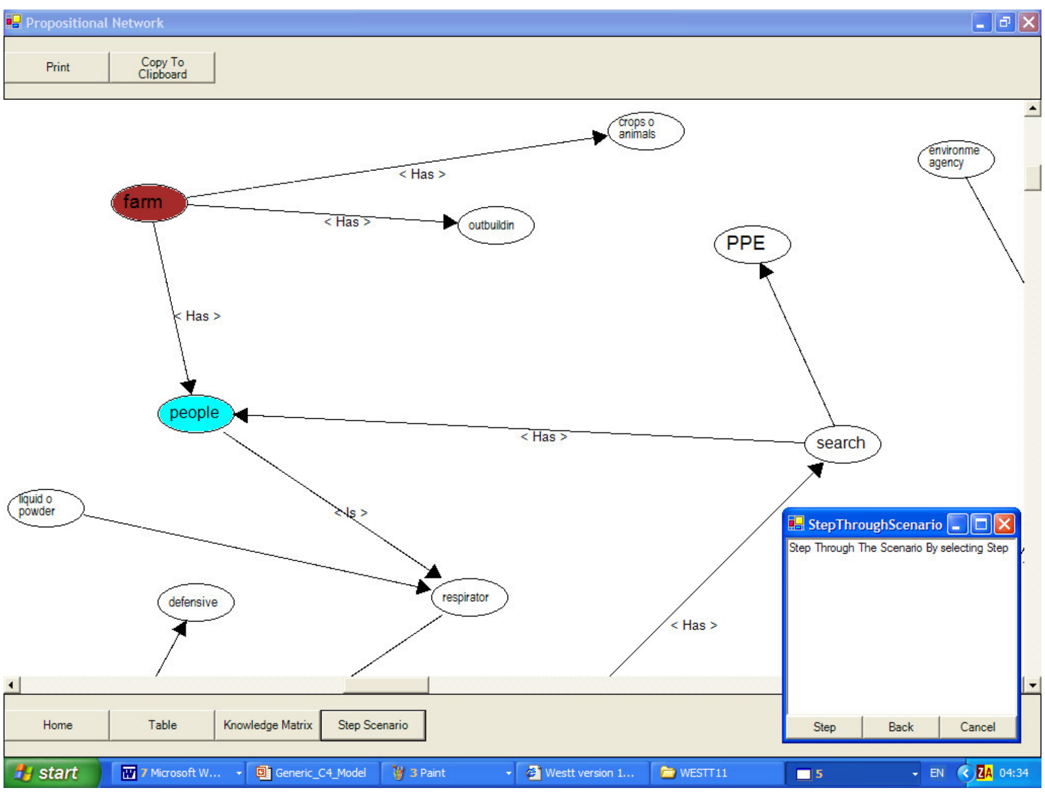


Figure 8. Propositional network of knowledge items and scenario playback controls.

From a theoretically agnostic perspective, the propositional network approach to the analysis of tasks and incidents produces data regarding which information is most important (and to whom) at different points over time and also serves to give a fuller description of the tasks to which it is linked, so it is not necessarily the case that our explanation of what this means be accepted fully for this to be a useful feature of WESTT as a software tool. However, from a theoretical perspective we are prompted to ask what it is in semantic terms that we are representing. If we argue that we are identifying who at different points in time makes use of different knowledge objects and that these are the focal points that the distributed cognition system is concentrating upon, then we can argue that the dynamic pattern of activation within the propositional network represents something akin to a system level depiction of situational awareness. To unpack that slightly; the 'situation' is modeled in terms of the knowledge objects in the propositional network itself and the 'awareness' (which changes over time and differs between actors) is the pattern of activation within the network. It is a point worth referring back to in our earlier discussion that the 'mental state' of a distributed cognitive system is an emergent property of that system and is not necessarily held, mirrored in or apprehended directly by any one individual. In some instances, a knowledge object will be activated by more than one agent. This would indicate the potential for sharing that knowledge object, but this need not imply that 'sharing' will result in communication or shared understanding. For example, different agents might activate a knowledge object from different perspectives or for different reasons, which could result in different interpretations or uses of that knowledge object. This suggests that the concept of 'shared awareness' is richer than simply assuming mutual knowledge or shared understanding. Rather, a knowledge object can be jointly activated, can be interpreted in different ways and can be communicated (or not) between agents. At the present time WESTT offers no clear guidance on this issue (and it is not clear to us at the present time if indeed it should) but in practical terms an analyst can get a qualitative feel for the context of activation by double clicking on an activated knowledge object which is hyperlinked back to the main data table screen with the appropriate phase of the operation clearly marked. Just as a social network cannot be fully understood without careful reference to the situation that produced it (and, we hold, vice versa), we feel that the same is true of our propositional network of knowledge.

Workload, Error and Time metrics.

The final part of WESTT is the calculation of workload, error and time metrics. All three metrics may constrain, from a Human Factors perspective, the design of a mission or set of procedures. A high combined error probability score for a procedure may render it too risky and too high a workload score would indicate the placement of sizable burdens upon human (or even technological) agents. Time as a metric differs slightly in that it indicates, in theory, the extent to which a set of tasks might under or overrun. Clearly one might want to take a careful look at events or procedures where a delay would be a critical problem. Combining measures of error and time can create a probabilistic 'worst case' analysis showing how a goal-oriented task might overrun in a percentage of cases after an error occurs and must be recovered from. Whilst WESTT does not directly make predictions about operational effectiveness *per se*, clearly time scale and the risk of human/technical error are factors worth considering when contemplating the chance of success a mission or activity has. In terms of the software itself, this process of metric generation is done by combining the data about what tasks are performed by who (as found in the main data-table and as depicted in the OSD and Use Case figures) with databases of the time tasks typically take to perform and the probability of error. The first advantage of using this “plug-in” database approach is that one can use existing data that have already been extensively validated and which make WESTT on some level compatible with other forms of analysis which use the same databases. The second advantage of this approach is that one can also produce and modify databases not just for human agents but also technological agents (e.g., an automatic targeting system) that define their different estimated error rates and task completion times. In general by making the database system extensible individual users can to some extent tailor WESTT to their particular specialist needs.

At present, for human agents, we are using The University of Birmingham’s CORE-DATA (Kirwan, Basra & Taylor-Adams, 1997) to provide Human Error Probabilities (HEP) for specific tasks. These HEPs can be used to populate fault trees in order to calculate approximate error rates for specific combinations of tasks. In WESTT, an Operation can be broken down further into a set of discrete tasks, and the HEP of each task used to calculate overall error rate (e.g., a transmit operation on the main data-table might break down into entering a sequence of digits into a mobile phone, speaking and then pressing the end call button).

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 of 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 individual 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 algorithm is WESTT will take into account the number of knowledge objects (as represented in the Propositional Network) to provide a scaling factor for the operations demand. Presumably a task that requires many knowledge objects is one that requires the individual(s) performing it to know many things. As such we might therefore expect it to be a cognitively complex task. It is conceivable that this may not always follow and so we are investigating at present the practicalities that surround this idea.

Given that each operation is made up of specific elements, the assignment of time to tasks in simply a matter of looking values up in the database. WESTT can combine these times into a simple linear model of individual time-on-task, i.e., by summing all the times in manner that is similar to keystroke level models which might also be taken as an indicator of workload (e.g., Card, Moran & Newell, 1983). As an alternative we are currently implementing a 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.

Discussion and conclusions.

This paper has described the design and use of the WESTT software tool together with an extended account of perhaps its most controversial feature, a propositional network representation of system situation awareness. WESTT is a desktop tool that allows an analyst to investigate and measure aspects of team performance beginning with a table of events which may be freely modified. WESTT combines three types of network; a network of tasks, a social network of agents and knowledge network. In addition to this WESTT also brings to bear existing forms of analysis of workload, error and task duration. 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.

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 and abuses of social network modelling 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 "network of networks" as a whole. A further aim is to make more explicit the technical constraints that exist in designing NEC socio-technical systems. Networking technology itself is not as such explicitly described and would, for the time being, have to be included as a set of agents that received a communication from one agent and then relayed it, possibly via other intermediary agents that are part of the communication system, to another. These activities (transmit, receive, and store information) would have durations and error probabilities described in the appropriate task database. This might be an appropriate way to study such developments in some cases (particularly where the technology might be said to embody some degree of intelligence and internal complexity), but could become difficult or cumbersome to implement in large, complex scenarios. A possible way of including these communications constraints more easily within our construct is to allow the definition of a communications network (in appearance similar to the existing social network) that depicts the possible links between agents on the basis of what communications technology they carry and the tagging of those links with some indication of, say, bandwidth, latency, spectrum and communications protocol. The *social* network produced from observations could then be compared with this *communications* network to give a measure of network usage (this would have the useful side effect of also suggesting to the analyst alternative routes communications might take that are not being exploited). Communications between agents are already tagged with their mode of transmission (e.g., verbal, electrical and mechanical) in the main data-table and through the CASA data collection tool and this taxonomy could be extended to encompass more specific types of information transfer technology. With this in place it could act as a constraint upon some scenario/operational designs and allow one to examine more fully the nature of communications flow within the system as a whole.

Acknowledgements.

The authors would like to thank West Midlands Police, UK, and the Fire Service Training College, Moreton-in-Marsh, UK, for their assistance. We would also like to thank Roland Edwards of DSTL, UK, and our Track Leadership for the 10th ICCRTS for useful comments regarding previous drafts of this paper.

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