WESTT: Reconfigurable Human Factors Model for Network Enabled Capability[1]

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SUMMARY

In order to explore the potential impact of novel command 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 of the performance of the system and on the agents operating within the system. The aim of the WESTT analytical prototyping tool is to support system analysis and to allow the analyst to explore the impact of reconfiguration through the manipulation of models. In this paper we describe the requirements, development and initial prototype of the WESTT system and illustrate the use of the tool through an example drawn from emergency service operations.

1.0 INTRODUCTION

This paper describes the development, functionality and application of the WESTT[2] human performance modelling system. The aim of the work is to produce a means of modelling Command, Control, Communications, Computer, Intelligence, Surveillance, Target Acquisition and Reconnaissance (C4ISTAR) activity within network-enabled capability (NEC) systems. The resulting models allow the exploration of novel system configurations such as those that may be encountered in combined military operations and / or when new NEC technologies are introduced.

WESTT represents operational activity at a systems level in which both humans and NEC technologies are represented as agents whose activity can be considered over time, as social networks and as propositional networks of knowledge items. The purpose of the WESTT system is to two-fold:

(i.) to represent observational data from field studies of existing systems;

(ii.) to provide a reconfigurable representation of systems, i.e., to allow analysts to modify the system description in order to explore the consequences of alternative designs.

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[2] The acronym WESTT stands for Workload, Error, Situational awareness, Time and Teamwork.

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WESTT provides a means of evaluating systems-level descriptions of operations with a view to supporting analytical prototyping. Analytical prototyping, developed by Baber and Stanton [1, 2], is based on the concept that initial system descriptions can be quantitatively explored in order to evaluate the potential benefits of modification. 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; with each modification, the resulting system can be quantified and compared with the initial description in order to evaluate the scale of likely improvements.

2.0 OVERVIEW OF WESTT

The WESTT system is designed to be an integrated suite of data collection and analysis tools. Data can be collected in the field using the C4I Activity Sampling Application (CASA). This is described in section 2.1, but basically comprises a .net application running on a Hewlett-Packard iPAQ™ that allows the analyst to tap buttons corresponding to observed activity, and then saves the data in a Microsoft Excel™ spreadsheet that downloads to the Personal Computer running WESTT. The WESTT application (described in section 2.2) then opens the spreadsheet and allows the analyst to view automatically constructed representations in the form of Operation Sequence and Social Network diagrams. The WESTT application also allows additional information to be added to the observed data, such as human error probabilities or predicted times for specific tasks, and allows the analyst to produce propositional networks to represent knowledge objects used by the agents (see section 3.3).

2.1 CASA

The C4I Activity Sampling Application (CASA) is designed to support the collection of data for building Operation Sequence Diagrams (OSD). The use of OSD has been widespread in the ergonomics community since the 1950s and provides an excellent means of representing the activity of agents within a system over the course of a mission. As Meister [3] 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.” [Meister, [3], p. 67]. Typically, OSD represents activity in terms of specific, discrete operations that are represented symbolically in the resulting diagram (see section 2.2). For CASA, the operations are used to define specific buttons on the ‘activity sampling’ screen (see figure 1).

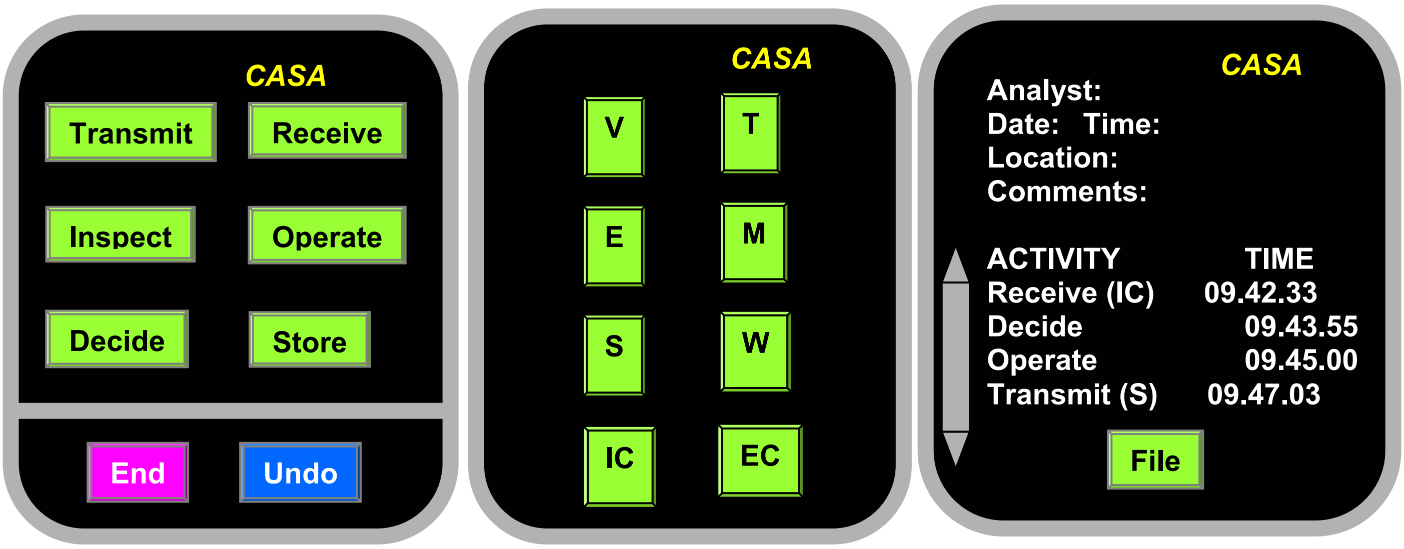

Figure One: Layout of Screens for CASA Software showing OSD sampling, Communications Media and Overview screens

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, Hand delivered. Selection of Medium then takes the analyst to a further screen to allow selection of the agents involved in 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 the observations. The presentation of the observations in this format allows initial review of the data. The button labelled 'File' takes the analyst to a further screen, which allows an Excel™ file to be created, named and saved. When the iPaq™ is placed in its cradle and ActiveSync™ operated, the Excel™ file will be uploaded onto the host PC.

2.2 WESTT

WESTT (Workload, Error, Situation Awareness, Time, Teamwork) is designed to support construction of system-level representations of a mission, and to enable the analyst to explore activity of the system and the agents within the system. Each aspect of system operations is described in terms of specific metrics (see section 3.0), which allows an objective analysis of different system configurations.

Figure 2 shows an overview of the system. The data from CASA are imported into the WESTT table. This table can be edited by the analyst, e.g., the observations can be broken into 'phases', tasks or knowledge objects can be added to each operation, or the agents performing operations can be reassigned (in order to reconfigure the system). This Data Table is then used to construct different representations, i.e., through OSD and Social Networks. Additional information can be added through the Task Database and the Propositional Network.

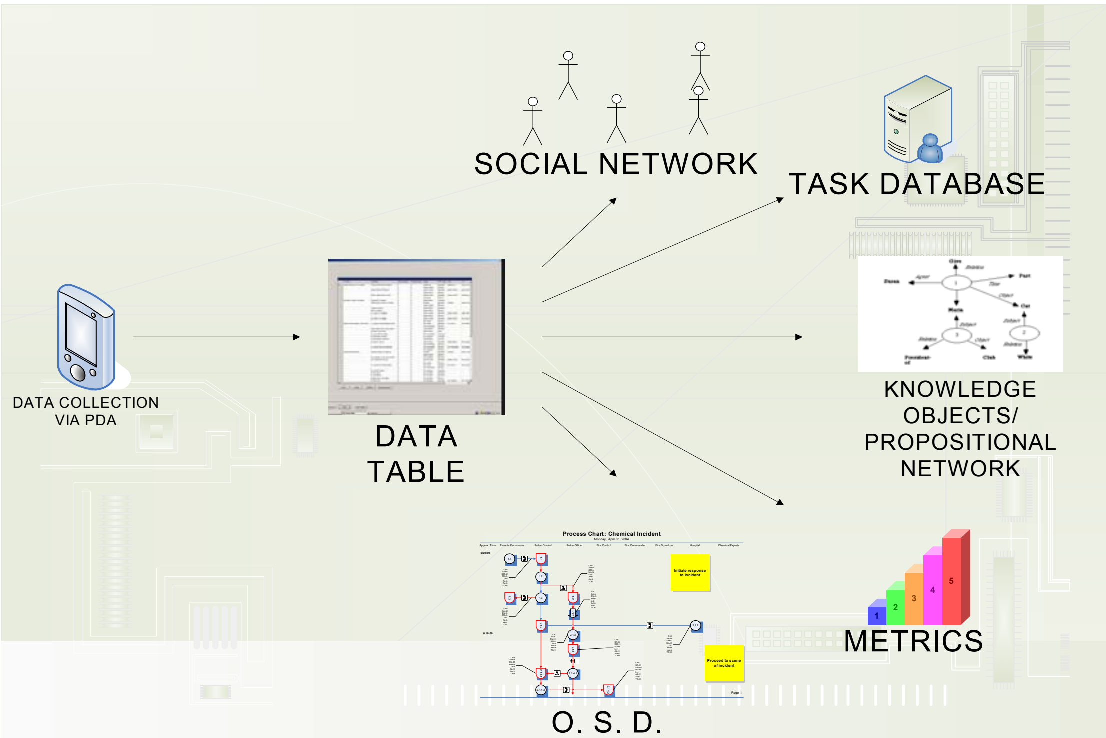

Figure 2: Overview of WESTT architecture

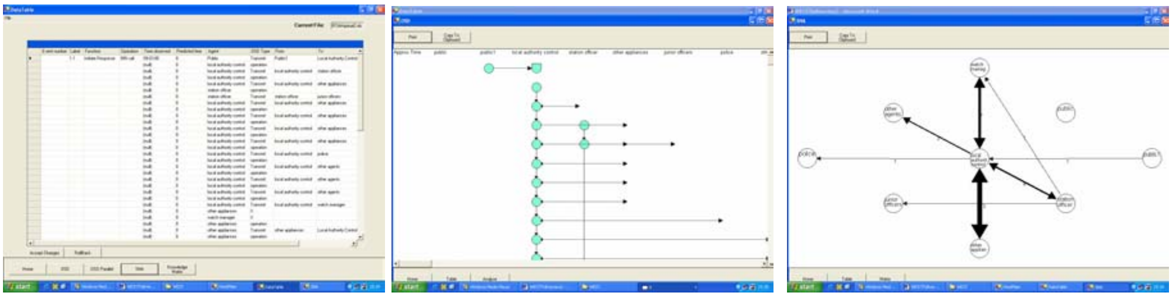

Figure 3: Screen shots of WESTT interface showing (from left to right): Data Table, OSD and SNA

The WESTT table links to the OSD and SNA diagrams (see figure 3) which provide different systems-level views. The OSD provides the analyst with a representation of operations x agents over time. Meister [3] notes that "…the task of drawing a complex OSD can be extremely cumbersome and expensive." [Meister, [3], 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 is able to construct the OSD immediately from the data supplied. The Social Network diagram indicates the interconnections between agents within the system. This allows subsequent analysis of the network configuration (see section 3.5).

In addition to importing and representing the observation data, WESTT supports the construction of 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. A knowledge object is an entity that plays a role in the mission and about which the agents need to acquire and use information. For example, in a road traffic accident, knowledge objects might include {location of accident, vehicles, road conditions, passengers…etc.}. In WESTT, the knowledge objects are entered into a matrix which allows the analyst to define the relationship between the objects, e.g., in terms of such terms as 'is', 'has', 'requires', 'knows' etc.

The terms used to define the relationship between knowledge objects forms the basis for a directed network. This provides a graphical representation of the 'space' of knowledge objects that are involved in the mission. 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.

3.0 METRICS

In order to analyse the data in WESTT, a series of metrics are being developed. These metrics provide an objective means of comparing systems, such as for Network Enabled Capability. In work based around agent-based automated simulations, Dekker [4] has suggested a set of metrics based upon social network theory that encompass information flow, co-ordination and the quality of intelligence. These metrics are rooted in the nature of the simulation itself. However, we have taken inspiration from the Dekker's ideas, namely that social network analysis can produce useful metrics of C4ISTAR architectures, and modified them for use with the real-world data WESTT is designed to use. This work is discussed below under the heading of teamwork.

METRIC CATEGORY	CALCULATED USING	WEST SCREEN
WORKLOAD	Number of tasks and their complexity (Knowledge objects)	TABLE / KNOWLEDGE OBJECTS
ERROR	Human error probabilities	TABLE / TASK DATABASE
SITUATIONAL AWARENESS	Knowledge objects available / required + relative importance of those objects	KNOWLEDGE OBJECTS / PROPOSITIONAL NETWORK
TIME	Number of tasks and their duration	TABLE / TASK DATABASE / FIELD DATA
TEAMWORK	Various social network measures	SOCIAL NETWORK

Table 1: Metrics used in WESTT

3.1 Workload

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. Megaw [5] provides a recent review of these metrics. 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 [6]; this could be considered as a function task scheduling [7] or in terms of competition between cognitive resources [8]. 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 algorithm 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.

3.2 Error

Quantitative models of human error can be developed on the basis of Human Error Probabilities [9]. Data from accident reports and experimental observation have been collated into databases, such as The University of Birmingham's CORE-DATA [10] 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 task. In WESTT, an Operation can be defined in terms of discrete tasks, and the HEP of each task used to calculate overall error rate.

3.3 Situation Awareness

WESTT makes use of a novel concept of Situation Awareness. Rather than focussing 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. These objects are represented in the form of a propositional network. Propositional Networks (PN), are used to represent the main 'objects' of information processing within the system, derived from a structured analysis of critical incident interviews. Nodes in a PN can be easily be associated with specific agents (as shown by the colour coding in figure three). 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.

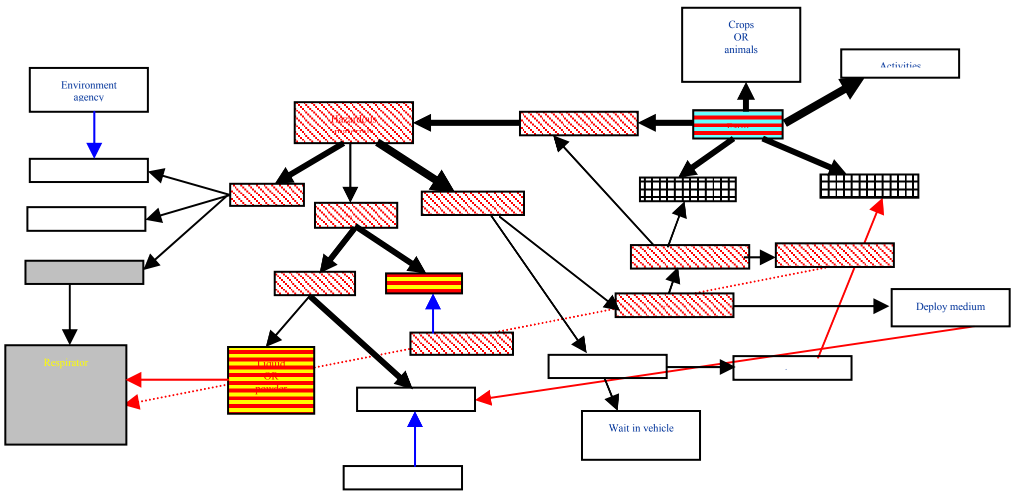

Figure 4: Propositional Network showing different agents ownership of knowledge objects (white = 'unowned'; shaded = fire; grid = police; grey = medical; striped = shared objects)

3.4 Time

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 [11]. The intention is to expand this analysis into a critical path model [12; 13] which can better account for the parallelism of human and system activity.

3.5 Teamwork

Teamwork is explored through concepts from Social Network Analysis [14]. In particular, we are currently exploring three metrics: Sociometric Status, Geodesic Distance and Centrality. Each metric provides a different perspective on the structure and performance of the social network. Sociometric status represents that contribution that a given agent makes to the overall frequency of communication activity within the network. To some extent it is analogous to workload, in terms of 'operations demand', in that an agent with high status is likely to have many communication links. The concepts of geodesic distance and centrality 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 (‘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 current situation with the result that clumsy, uncoordinated or even hazardous actions are taken. Therefore, after Dekker [4], of particular interest are the geodesic distances between intelligence and command units (‘information flow’), the distance between command and force units (more generically, agents that initiate action) and finally, the distances between force units themselves (which Dekker’s simulations have implicated as important for the co-ordination of action). The final social network metric is centrality; the most central node in a network being the least distant from all others in terms of geodesic distance. This metric is useful in the rapid characterisation of a given agent’s role within a network; for example, if a command unit has relatively low centrality then it implies the network has a hierarchical structure with information and commands relayed to actors through intermediary units. Taken together the Teamwork metrics allow the analyst to gain a rapid understanding of the nature and structure of communications between agents and to be able to specify changes in a principled manner.

4.0 APPLICATION

In this section, an application of WESTT is presented. The application focuses on a scenario taken from Police Operations[3]. The incident in question is one of a number of ‘everyday’ operations that we have been observing over the past weeks. In the incident under review, a night porter reports a vehicle being broken into. A Call Centre arranges for a police car to be dispatched to the scene. The officers view CCTV footage and a crime reference number is generated.

The Police keep an Incident Log of all radio communications and this log, together with observations and interviews, forms the basis for the WESTT spreadsheet (see figure 5). The incident can be divided into five phases, which are added post-hoc and are intended to reflect the manner in which the incident unfolds. In addition to numbering of events and definition of phases, the analyst can also add items in a Coordination Demand Analysis. This provides a rating of each operation in terms of assessed workload, situation awareness, communication, management etc.

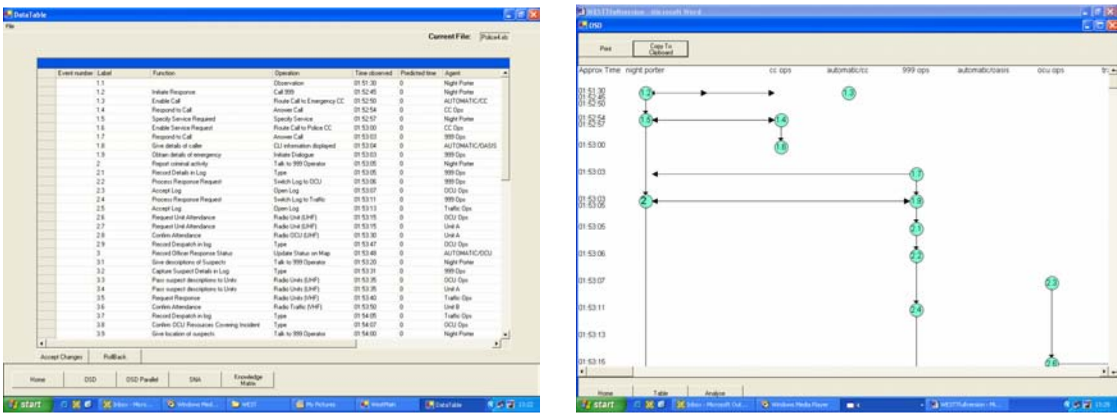

Figure 5: Main Data table and OSD screens

The table is used to produce an Operation Sequence Diagram (figure 5) and a Social Network Diagram (figure 6). The three representations (table, OSD and SNA) form the first pass analysis of the incident and provide the analyst with information on the way in which the system is configured and operates.

[3] We are grateful to Richard McMaster for providing some of the observational data for this analysis

The operations in the OSD can be used to provide an initial approximation of effort for each Agent. From this analysis we can produce a summary of operations (see table 2). The summary of operations provides an overview of the operations performed by the different agents in the system and indicates that, for instance, the '999Ops' and 'OCUOps' have a much higher level of activity than the other Agents in the system. The explanation for this result is simply that these Agents are co-ordinating the mission from their respective control rooms. By comparing the number of operations over each phase of the incident, it is also possible to produce initial plots of 'workload' for the different agents. This provides an indication of where likely pinch-points might be in terms of demand and gives an insight into possible sources of variation in workload.

Agent	Operation	Transmit	Decision	Receive	TOTAL
999Ops	12	3		12	27
OCUOps	17	16	2	15	50
Automatic/CC/OCU	6		1		7
NightPorter		11	1	4	16
All Local Units				8	8
All Traffic Units				3	3
CCOps	1	1		2	4
Garage				1	1
UnitA				6	6
UnitB				1	1
UnitC				3	3
TrafficOps	2	4	1	4	11
UnitA		15			15
UnitB		3			3
UnitC		3			3

Table 2: Summary of Operations

The Social Network Analysis can be analysed in terms of Sociometric Status, Centrality and Geodesic Distance. From the Social Network shown in figure 6, it is possible to see that there are three main sub-networks in this particular network. This is interesting and suggests that, while it might allow for efficient communication for the incident, there is the potential for the network to collapse if the situation changes. For example, it might introduce significant delays if one of the outer nodes needs to take charge of the situation.

The data used to construct the SNA in WESTT are (in the current version) exported to an Excel spreadsheet and then imported into a tool called AGNA[4], which is used to perform the calculations. From this analysis we can see that there is some variation in Sociometric Status. Table 3 shows the calculated Sociometric Status. In broad terms, the greater the number, the greater the contribution an agent makes the functioning of the network. From table 3, it is apparent that the Sociometric Status tends to fall into three distinct groups for this network. The Agents with the highest Sociometric Status are the OCUOps and the UnitA, which form part of the bottom triangle in figure 6.

[4] AGNA (Applied Graph and Network Analysis) is a platform-independent free software package available from the author on the world wide web at http://www.geocities.com/imbenta/agna/

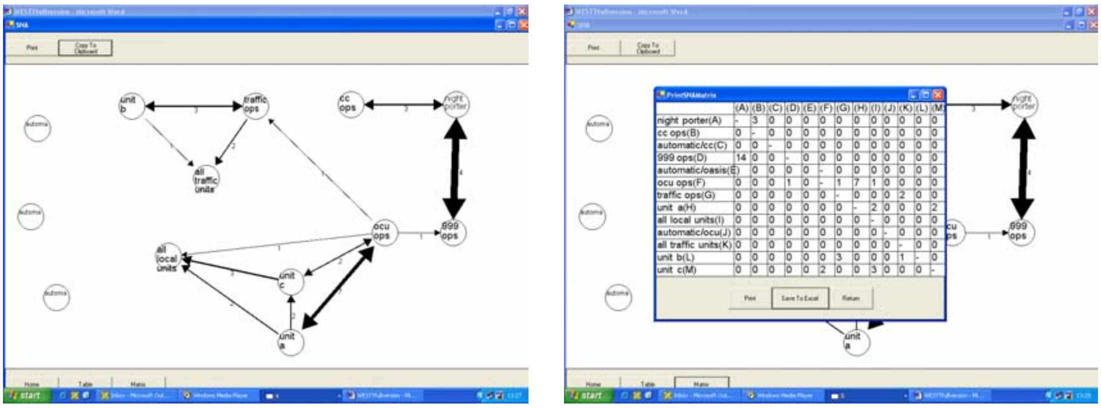

Figure 6: SNA and SNA Matrix screens

Table 3 also shows the results for Centrality measures. This indicates the distance from a given Agent to other Agents. The lower the measure the more 'connected' an Agent is to the network. From this measure, one can see that UnitA and OCUOps are key Agents, along with AgentC (which is part of the upper triangle in figure 6).

Agent	Status
OCUOps	2.4
UnitA	2.4
999Ops	1.5
NightPorter	1.5
UnitC	0.9
ALU	0.8
TrafficOps	0.7
UnitB	0.5
ATU	0.3
CCOps	0.1
Garage	0.1

Agent	B-L Centrality
UnitA	2.857143
UnitC	2.857143
OCUOps	3.5294118
NightPorter	5.4545455
UnitB	5.4545455
ATU	6.0
999Ops	6.6666665
TrafficOps	7.5
Garage	10.0
CCOps	20.0
ALU	20.0

Table 3: Sociometric Status and Bavelas-Leavitt Centrality measures

In addition to analysing the activity of the system, WESTT also supports the construction of a propositional network, which describes the knowledge objects employed by the Agents in this incident. Figure 7 shows the Knowledge Object table created by the analyst using WESTT and figure 7 shows the resulting Propositional Network.

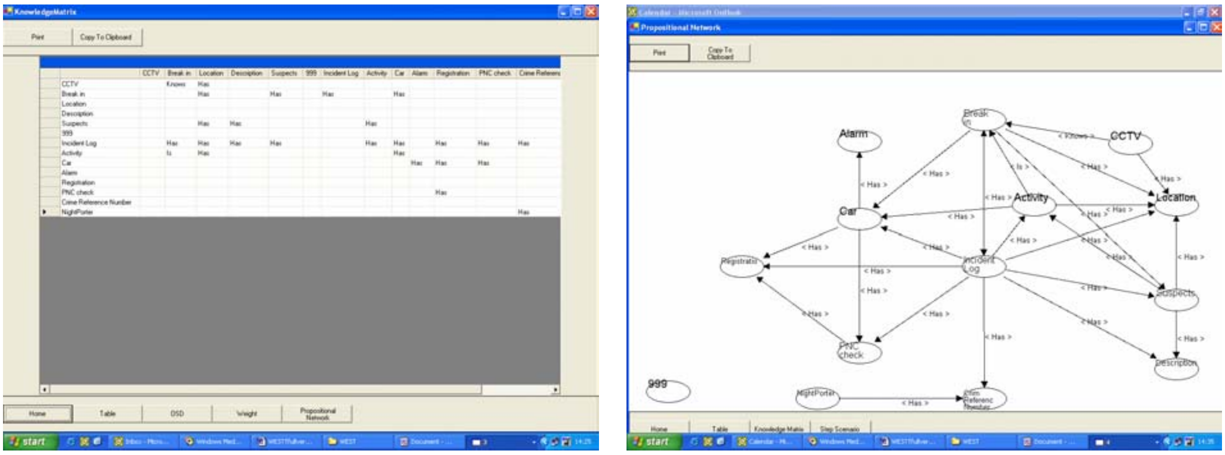

Figure 7: Knowledge Objects Matrix and Propositional Network

5.0 DISCUSSION

This paper has described the design and use of the WESTT analytical prototyping tool. It is envisaged that WESTT will provide a novel and useful means of representing NEC, and be particularly beneficial for exploring future configurations in 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.

A WESTT analysis can be used to indicate barriers to force interoperability such as deficits and asymmetries in expertise and situational awareness, pinch-points and sub-optimal social and communication network configurations. Specifically, the analysis is designed to focus on the 'system' level, through the use of Social Network Analysis, and on the 'agent' level, through consideration of workload, situation awareness, time and human error potential.

6.0 REFERENCES

[1] 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

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

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

[4] Dekker, A. H. (2001). Applying Social Network Analysis Concepts to Military C4ISR Architectures. *Connections*, 24 (3), 93-103.

[5] Megaw, E.D. (in press) The definition and measurement of mental workload, in J.R.Wilson, E.D. Megaw and E.N. Corlett (eds) *The Evaluation of Human Work*, London: Taylor and Francis [3rd edition]

[6] 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

[7] 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

[8] 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

[9] Kirwan, B. (1992) *A Guide to Practical Human Reliability Assessment*, London: Taylor and Francis

[10] Kirwan, B., Basra, G., Taylor-Adams, S.E. (1997) CORE-DATA: A Computerised Human Error Database for Human Reliability Support, In D.I. Gertman, D.L. Schurman and H.S. Blackman (eds) *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, New York: Institute of Electrical and Electronic Engineers

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

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

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

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