Applying Cognitive Work Analysis to Event Management

Khanh Bui
Northrop Grumman
Chantilly, Virginia
Khanh.Bui@ngc.com

Roy Taylor
Northrop Grumman
Orlando, Florida
Roy.Taylor@ngc.com

ABSTRACT

Operations for simulated mission events include all activities required in orchestrating test and mission events during simulation-based training for the Combat Air Force (CAF) in the Distributed Mission Operations (DMO) environment. In contrast to the quasi-static pre-event and post-event processes that can readily be harmonized, the event itself unfolds in a more fluid and dynamic manner that requires real-time participation of experts including event conductors or managers. An event manager must possess multiple technical and operational skills to successfully monitor and control network traffic flows between sites, at possibly different security domains, to ensure that standards for secure operations, situation awareness, coordination and communication, as well as customer expectations, are consistently met.

This paper presents the initial results of applying the Cognitive Work Analysis (CWA) framework in this arena. Specifically, it focuses on the activities, decisions, strategies, co-operation, and competencies of event managers, to understand and represent why, what, where, when, how, and with whom activities can be performed. The results of these investigations which were created, verified, and refined using reference documentation, subject-matter-expert (SME) interviews, field observations of SMEs-in action, and table-top-analyses, are captured in checklists, standard operating procedures, and suggested training reference materials for use by event managers. The products derived from applying CWA are particularly useful because of their flexibility. They can be used by workers at different levels of proficiency, are adaptable to technological or architectural changes, and are scalable to accommodate increased numbers of events operating in parallel in cryptographically separate security domains.

ABOUT THE AUTHORS

Khanh Bui is a Principle Security Engineer at Northrop Grumman with over 20 years of industry experience in systems engineering, information assurance, process improvement, and technical leadership. She holds a Ph.D. in Information Technology and a M.S. in Computer Science from George Mason University, Fairfax, VA. Khanh is a Certified Information Systems Auditor (CISA), a Certified Information Systems Security Professional (CISSP), an Information Systems Security Engineering Professional (ISSEP), a Certification and Accreditation Professional (CAP), and a Six Sigma Black Belt.

Roy Taylor is a Network Engineer at Northrop Grumman with 18 years experience in systems operations, network operations and information management. He is currently the lead for the NOC and DOC operations in support of the Air Force Distributed Mission Training Program. Roy holds a B.S. in Information Systems Management from University of Maryland, Adelphia, MD and is a Six Sigma Green Belt. He has over 30 years of experience in working with and in and supporting the military.

Applying Cognitive Work Analysis to Event Management

Khanh Bui
Northrop Grumman
Chantilly, Virginia
Khanh.Bui@ngc.com

Roy Taylor
Northrop Grumman
Orlando, Florida
Roy.Taylor@ngc.com

INTRODUCTION

This paper summarizes initial results of applying the Cognitive Work Analysis (CWA) framework to the domain of event management at the Distributed Mission Training (DMT) Operations Center (DOC) in Orlando, Florida. There were two objectives of the study. The first was to use CWA to identify the activities, decisions, strategies, co-operation, and competencies of the event mangers who plan, start up, execute, and shut down training events. The second was to assess the ability of CWA to produce a unified representation of event control and operations. Such a representation can be used to efficiently create reliable artifacts that facilitate the seamless execution of cross-site events within the Distributed Mission Operations Network (DMON) infrastructure.

CWA, rooted in cognitive systems engineering, has been used to execute the analysis, design, and evaluation of complex socio-technical systems that challenge the need to better support operators for performing effectively under unanticipated conditions (Jenkins et al., 2009). The framework models the work domain and uncovers constraints that define the boundaries within which workers operate (Roth, 2008). The constraints are progressively added through applying five layers of analysis: *work domain, control task, strategies, cooperation,* and *worker competencies* (Vicente, 1999). In this paper, the authors also use other methods originating in Control Task Analysis (CTA). These methods include the techniques of *concept mapping* and research results on the basis of expertise that distinguish experts from novices (Crandall et al., 2006) applied to this work domain, control task, and competencies analysis. According to Roth (2008), both CTA and CWA, or, in general, Cognitive Analysis methods extend traditional task analysis techniques to reveal the knowledge and strategies that underlie performance in cognitive complex settings. The CTA "inside-out" approach focuses on the deep cognition and critical decisions underlying expert and error prone performance. In contrast, the CWA "outside-in" method begins with the domain's environmental characteristics and gradually transitions to cognitive constraints (Vicente, 1999). Based on this initial investigation, the CWA, extended with CTA methods, appears to play an important role as a "capability multiplier" helping simulation support professionals to perform at a high level in this cognitively complex environment.

This article discusses three application areas:

1. *Checklists and Procedures*: The CWA approach proved useful in creating tailored checklists from core CWA products. This was done without the need for deep expertise in event operations. The correctness of the resulting checklists was established by comparison with expert-generated checklists.

2. *Event Management Gap Analysis Across Event Types*: The CWA approach was useful in understanding the activities required across different event types so their relative complexities could be identified. The case considered relates to single- and cross-domain events.

3. *Training Needs and Training Materials*: The trend toward increasing simulation complexity makes concomitant demands on the event managers and operators. Because of its comprehensive and flexible representations, CWA can support the development of training to improve the competency and performance of event managers and their support crewmembers.

CWA for SIMULATION SUPPORT

Current trends in simulation make the simulation support job increasingly more challenging. Simulation support is becoming more important and difficult to execute, and the cost of errors is rising. CWA, a system analysis tool to cope with complexity (Jenkins et al.,

2009) and human errors (Rasmussen, 1986), is a useful method for use in simulation support generally, and for use in the DMON event management in particular.

Simulation Support is Increasingly Important and Difficult

Northrop Grumman architects the DMON and provides operations and integration services, connecting virtual (e.g., high fidelity flight simulators) and constructive (e.g., computer generated forces) elements of simulated conflicts over both local and wide area networks. Linked via the DMON infrastructure, personnel at Air Force bases around the world can practice their combat skills and rehearse missions routinely in a common synthetic battle space as if they are in the actual war fighting environment (Djahandari, et al., 2009). These personnel include pilots, weapon systems officers, and command, control, intelligence, surveillance, and reconnaissance (C2ISR) crew members.

As new, more complex simulator platforms are created, new sites are stood up, and more multi-national partners are engaged in increasingly sophisticated training exercises, the extent of future interconnections becomes enormous. An initial live component has already been added to the virtual, constructive environment of DMON in the case of Pacific Air Forces (PACAF) training ranges (Marsden, et. al., 2009). If, or more likely, when, the DoD begins to broadly employ Live, Virtual, Constructive (LVC) simulations, and live aircraft are on the network, then the simulation community will have a whole new level of performance to deliver. Currently, the air traffic / airspace control community has a very rigorous procedural work environment, and it is conceivable that LVC simulation control centers will need capabilities delivering similar reliability.

To date CWA has been applied successfully in many domains where the system is complex and the cost of failure is high. These include: Air traffic control (St-Cyr et al, 2008); aviation (e.g. Sanderson 2003); military command and control (C2) (e.g. Jenkins et al., 2009); health care (e.g. Burns et al., 2004); and process control (e.g. Vicente, 1999). CWA has also been used for designing safe and effective future Unmanned Aerial Systems (Elix & Naikar, 2008); analyzing information associated with operators' decisions in using C2 systems including Time Critical Targeting Functionality (TCTF), Joint Surveillance Targeting Attack Radar System (JSTARS), and Airborne Warning and Control System (AWACS) (Means & Burns, 2005). Bringing CWA to the operations center today is potentially a path to guide that giant leap into the important future with LVC control centers.

Simulation Support is More Intolerant of Error

The two most significant costs of simulation support errors are lost productivity and security errors. The more sites and security levels involved in an event, the more complicated and time-consuming the diagnosing and fixing of a problem becomes. If a simulation's start is delayed, its execution interrupted, or it ends prematurely, then the productive activities of all simulation participants, some employing expensive hardware and other resources, are wasted. Training must be rescheduled. If a security breach occurs, it will require lengthy and costly remediation. For example, affected facilities may need to be sanitized, and systems may require reaccreditation.

Realistic simulations may involve all actors including the Air Force, inter-service and coalition forces, and include comprehensive flows of communications, sensor data, and intelligence information to all participants. Therefore, the DMON simulation events must operate at a defined classification level with distinct hierarchical security domains (designated by colors). Realistic simulation training events require security mechanisms that can facilitate simultaneous operations in multiple security domains and, as in DMON, include the use of partitioning, encryption and Cross-Domain Solutions (CDS). A controlled interface (CI) implementing a CDS can modify or block specific security data to personnel who are not cleared to view or know the data. Currently, DMON event managers simultaneously integrate network operations for both single and cross-domain events.

Protection of classified data is the overarching concern of event managers. One specific concern is data contamination, i.e., data mistakenly allowed to flow to, and hence reside on, systems unauthorized to store or process that level of data. One cannot "un-ring the bell" if this happens. Sanitizing contaminated systems can be difficult and consume significant resources. Another specific concern is data spills, i.e., exposing classified information to personnel who do not have appropriate clearances, or having high-side data mistakenly accessed by personnel or processes in a low-side simulation role. Security mechanisms, such as those in the CDS, are used to maintain the simulation's security integrity. However, other mechanisms require actions and interventions by the event managers when the DMON goes on-line at sites.

The DMON Today As a CWA Application Domain

The previous subsections describe the case for using the formalism of CWA to address the challenging trends in the simulation and DMON world. However, the DMON as it operates today is already sufficiently complex to benefit from CWA. This section sketches the current DMON and what was observed as the "low hanging fruit" of this first application of CWA, namely operational checklists. The next section will describe these and other results in more detail.

The DMON can be configured to accommodate various types of stand-alone and distributed events. Types include site-to-site (peer-to-peer), multi-point (one site or enclave engaged with another site or enclave), and simultaneous (multiple, non-interacting events occurring simultaneously and partitioned using separate cryptographic keys). For a single level event, the sites operate together in the same security domain (i.e., one color). A cross-domain event allows interactions between sites operating at different security domains during the same event. Currently, this is limited to be between one high side or enclave (multiple sites) and one low site or enclave, or between two sites or enclaves, operating separately without connectivity between them at different colors, connecting to a common, low, third-color site or enclave. Developing the capability to support other configurations is underway.

In addition, a DMON event can be configured based on a complex range of options or specifications defined for a training scenario. The varied elements that drive the dynamic system configuration and work function allocation include:

- Simulation participants (federate, federation);
- Security domains (single domain, cross-domain);
- An approved combination of colors representing cross domains (accredited rule sets that define the allowed data interchanges based on security adjudication);
- Simulation protocols (PortalSpeak, HLA, DIS, TENA) for various simulator platforms;
- Data separation mechanisms (partitioning, encryption, filtering);
- Connectivity for different types of traffic flow (control, crypto, simulation);
- Devices (encryptors, routers); tools (security management, event recording and analysis); and
- Disparate technologies at the sites (e.g., Brief-Debrief capabilities).

The event manager and operations staff must accommodate and support the complex and dynamic variability in DMON-based events described in the preceding two paragraphs. The authors were led to CWA during their search for techniques that would bring some rigorous and comprehensive order to the task. According to Jenkins et al. (2009, p11), "CWA is particularly appealing as it can be applied in both closed systems, in which operations are predictable and options for completing a task are normally limited, and open systems, in which task performance is subject to influences and disturbances that cannot always be foreseen". The latter case applies to the highly dynamic DMON domain and in this study was perhaps best illustrated by the creation of context-dependent operator checklists with different branches depending on the dynamic system state.

CWA helps to identify the constraints that bound the solution space for supporting DMON events. Within that space, CWA models how work can be done. The work patterns that emerge reveal many different tasks or task sequences, including some that are otherwise difficult to prescribe or specify up front. The CWA analyst must systematically analyze the work domain to determine these constraints (Burns et al., 2004).

CWA provides a comprehensive catalog of work functions (activities expressed in terms of problems to solve) necessary for successful event operations. These are stable even under the ongoing and inevitable evolution of network implementation, or the changes in technical solutions driven by adding value to provide better services to the customer. As discussed in the recommendations from a recent process improvement report (DMT O&I, 2009), the event managers and the security engineers that support them need to understand the range of issues that can affect the outcome of an event, and they need to possess good troubleshooting skills. It is anticipated that the CWA products represent some collective knowledge, some internal "know how" specific to event operations, and are thus a first step toward supporting a goal of program-wide knowledge sharing and training.

It is straightforward to translate how work can be done into how work is currently done, i.e., reflecting present operational practices and technological or architectural considerations. A checklist is viewed as an instantiation of how work can be done. In addition, checklists can be tailored to specific work situations. For example, checklists can address phases of an event (e.g., planning, start-up), event functions (e.g., event control, technical operations), event management roles (network, security engineering), and the complexity of an event (e.g., single or cross-domain, number of sites). In the next section checklists will also be seen to be the mechanism for encoding the valuable shortcuts used by experts.

APPLICATION of CWA and RESULTS

This section describes the main results of the study obtained by applying five portions of CWA/CTA. These are as follows: Work Domain Analysis (WDA), Concept Mappings, Control Task Analysis (ConTA), Strategies Analysis (StrA), and Worker Competencies Analysis (WCA).

WDA to Understand Activities Performed Across All Types of Events

WDA provides a framework for analytically deriving work functions performed by people or machines. These are viewed as constraints of the system being controlled and are captured in an abstraction hierarchy (AH). Given the limited access to expert event managers, and given that their knowledge of the constraints affecting the system is mostly tacit, the first author used documentary sources to discover these constraints prior to refining them with expert inputs. Consulted references included CAF DMO standards, functional specifications, user guides, certification and accreditation documents, and the DMODMT website.

The authors used the AH and generalization-specification links to perform WDA and differentiate activities required across event types. Figure 1 shows a simplified portion of the AH (where some notional link arrows are shown pointing to or issuing from omitted nodes / hidden columns). Elements of the event management domain are ordered in five levels of abstraction. The highest level (Purpose) nodes represent the work necessary to orchestrate mission events during simulation-based training. At the lowest level (Physical Resources) nodes represent the devices, software, applications, objects, files, etc., used to accomplish the end purpose. Abstraction levels can be linked by *means-end* or *why-what-how* relationships. The descriptive content of a node in the AH can be examined to answer the question of *what it does*. Given a node of interest, (1) the nodes linked to it at the next higher layer answer the question *why it is needed,* and (2) the nodes linked to it at the lower layer answer the question *how it can be achieved* (Jenkins et al, 2009).

Activities for a non-CDS event and a CDS event are traced and instantiated from the AH and overlaid to highlight differences in red.

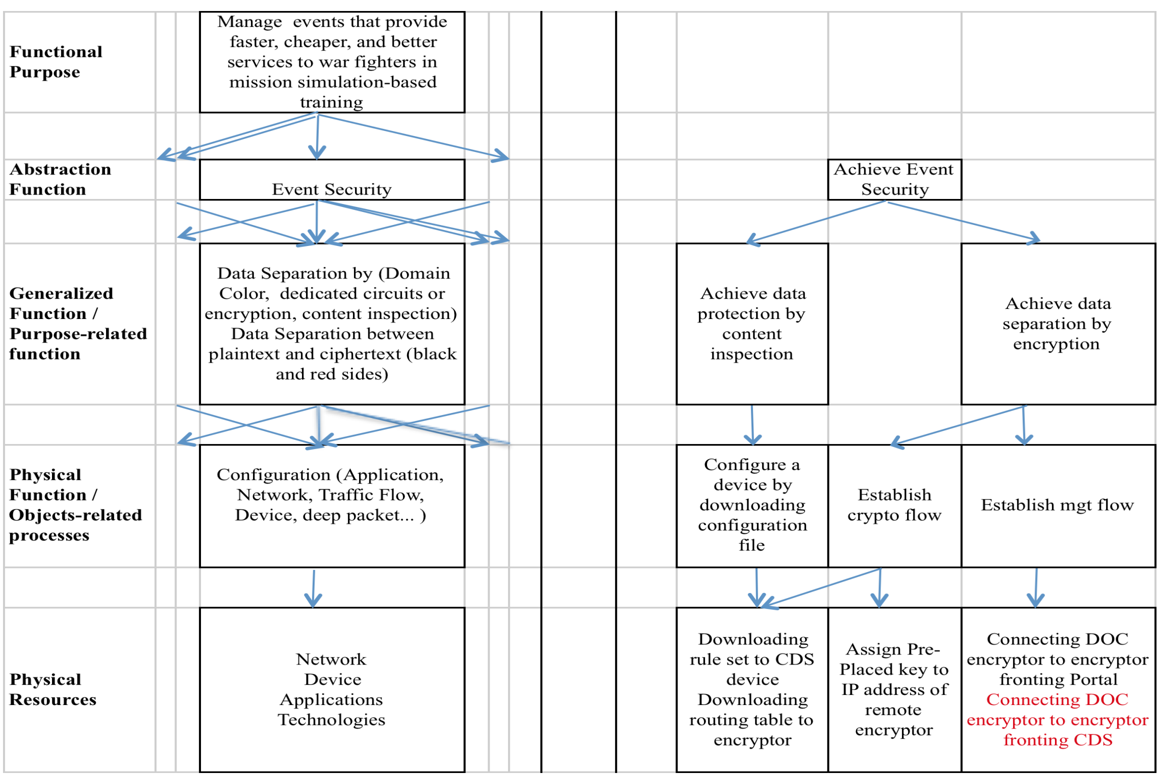

Figure 1. Simplified Abstraction Hierarchy and CDS and non-CDS Comparison

As a result of WDA, the AH contains a variety of knowledge about the work domain: knowledge about work function (nodes), intentional knowledge (means-ends), structural knowledge (wholes-parts, objects-attributes) and causal knowledge (interactions between subsystems). Here, the authors add another type of knowledge, generalization and specification, via ISA links placed over the physical functions and resources layers. For example, the physical function "configure a device" can be instantiated where Device = {Encryptor, Portal, CDS device}, e.g.., Encryptor ISA Device.

In both cases, the event manager ensures the network, devices, or applications are set up correctly to meet security and performance requirements, e.g., manually building routing tables prior to an event. However, security constraints require the routing tables not to be downloaded until the time of the event. The event manager then downloads routing tables and assigns traffic encryption keys once the site security readiness fax is received. According to the expert event manager, the second author, there is no difference in the complexity of this network setting for cross-domain or single level events. In the case of a CDS event, there is additional management traffic from the CI management system to the CI to activate it, but just like the common level event, there are special routes and keys used for these CI devices that minimize the chance of human errors due to manual processes of entering IP addresses and constructing routes.

ISA relationships (i.e., where $A \xrightarrow{ISA} B$ means "A **is a** B") allow for the exploitation of analogies between subsystems (e.g., management system for Portal, management system for CI), between versions of implementation (e.g., CDS, Portal), or between the current version of the system and a future, perhaps seemingly more complex, version of the system. Also, ISA links help structure a catalog of procedures that is cognitively relevant and easy to reference.

Concept Maps to Catalog and Suggest Procedures

Concept Maps are used to supplement the decomposition space by adding associated links to the last physical layers of ADS, to identify or suggest procedures, and combined with the AH, to perform WDA and represent a catalog of work functions necessary for a successful event operation.

Traditional CWA uses a decomposition space for encoding part-whole relationships, e.g., total system, subsystem, and component. Following Burns et al. (2004), the initial analysis included the decomposition of communication layers. These layers are system, application, network, data link, and physical. The last four layers are adapted from the International Standards Operations (ISO) - Open System Interconnect (OSI) model with one simplification. The application layer in this CWA study encompasses the transport, session, presentation, and application layers of the OSI model. However, as the work progressed, it was discovered that relationships other than "part-whole" needed to be captured, and Concept Maps were particularly well suited for that purpose. (For more on using Concept Maps for knowledge elicitation and representation, see Crandall et al., 2006).

To the extent possible, the four OSI layers help guide the construction of the Concept Maps, e.g., focus on *applications* (management systems, tools, software), *network* (types of traffic relating to accurate routing or key assignments), *data link* (security and performance requirements relating to deep packet processing), and finally, *physical* (e.g., types of switch ports and port assignments). Based on the Concept Maps produced in this study, a number of procedures were proposed.

Operating procedures are technologically and architecturally dependent because they describe the current implementations such as specific device model, selected tool, or user interface layout. Changes to a management system user interface, for example, may cause major changes to the steps in a procedure, but the fundamental target results of performing the activity will be essentially the same. A checklist item (activity or check) can be readily linked to detailed procedures. Procedures for complex activities serve as guidelines that inform operator behaviors, not as scripts to be mechanically followed. With subject matter expert (SME) involvement in their development, procedures have the potential to capture valuable operational expertise. An experienced operator's judgment is prized, even if it deviates from simplistic written procedures, because of the operator' ability to find short cuts or detours circumventing obstructions. Capturing and encoding expert decision processes in procedures is a long-term goal of this effort.

ConTA to Generate Checklists

While WDA represents the possibilities for action, independent of situation (e.g., event type), Control Task Analysis (ConTA) narrows the possibilities of action by adding constraints imposed by the control tasks.

This section describes how to use Decision Ladders (DLs), integrated with the Concept Map and AH, to perform ConTA and to generate checklists that help prevent critical cognitive issues from being ignored in the complex, dynamic, active, events conducted in the DOC. (A compelling story of the efficacy of checklists in the high-risk medical domain is in Gawande, 2007).

Consider the relationship and interactions between control tasks, the work domain, and Concept Map shown in the figure below. The work domain concerns the objects of action while control tasks describe the information requirements associated with expert control actions.

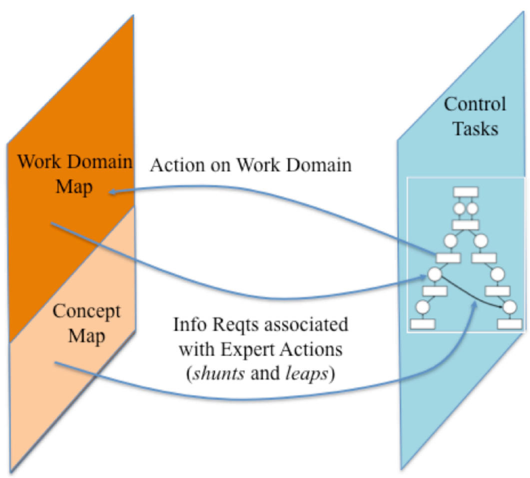

Figure 2. Work Domain and Control Task Relationships Identified by ConTA

The conceptual representation describing control tasks is the DL (See Figure 3). The template represents information processing activities (boxes) and resulting knowledge states (circles). The two types of shortcuts that can occur in the ladder are *shunts* and *leaps.* Shunts connect an information processing activity to a knowledge state (box to circle) and *leaps* connect two knowledge states (circle to circle). When a shortcut is taken, some information-processing activities are bypassed but the desired results are still achieved (Jenkins et al., 2009).

Mapping operator activities onto the various elements of the work domain allows the identification of information requirements associated with expert action (Vicente, 1999). These information requirements define essential elements for a checklist, that is, to ensure that the information associated with expert controlling action is ready and available for expert or novice operators to recognize and act upon. The most valuable information requirements enable the expert's shunts and leaps on the decision ladder. This observation also has implications for what checklist-encoded knowledge constitutes important training materials and what decision skills are desired as training outcomes as discussed in the WCA section.

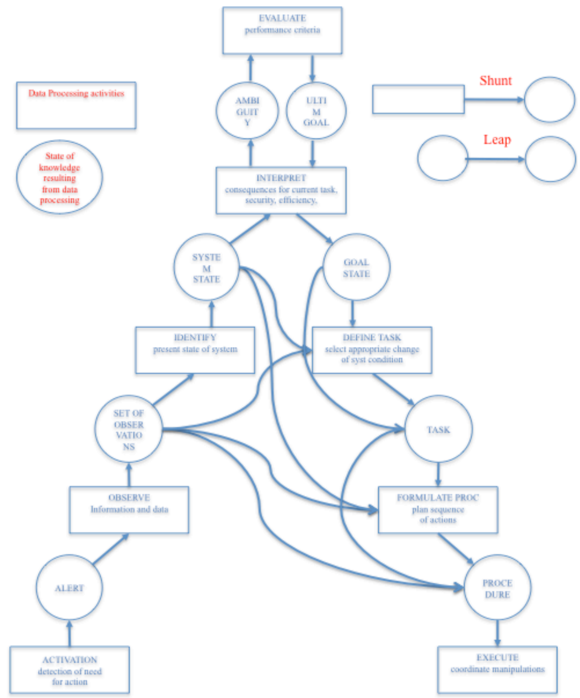

Figure 3. Decision Ladder Template (adapted from Jenkins et al 2009, p.28)

A ConTA analyst is not concerned with which person or machine performs activities. That aspect of decision-making appears in a later phase of analysis. However, the activities identified can be inputs to a process improvement effort in which laborious or error-prone human activities are considered for automation.

Note that checklists are not procedures. Checklists capture *what is to be done* and procedures show *how to do it*. This division has the benefit of isolating the more dynamic system elements in the procedures that the checklists point to. Thus, while architectural or technological changes often require changes to the procedures, or to the Concept Maps that describe physical objects and suggest procedures, the checklists remain unaltered.

Another potentially significant efficiency in using CWA is generating artifacts whose reliability and correctness seem largely derived from the one-time, or infrequent, vetting of higher-level core CWA products such as the AH, Concept Map, and Decision Ladder. Recent event outcomes prompted the formation of a

Tiger Team of expert event managers (including the second author) to develop checklists that would ensure the success of an upcoming event. This presented a real world opportunity to test the validity of a CWA-derived product. Independently, the first author (not an event manager) developed a checklist from the CWA artifact guided by the ConTA approach.

A comparison of the two checklists showed the CWA-derived list was sufficient and not missing any elements of the Tiger Team checklist. The CWA-derived checklist actually contained the Tiger Team list since the focus of the CWA analysis was on checking tasks critical to a successful event, not only the roles allocated to event managers. Task allocation happens in the later phases of CWA. Finally, as noted earlier, the CWA-derived checklists clearly separated the stable checks from the performance of implementation-dependent procedures that they referenced.

It is noteworthy that the CWA-generated list was produced without deep operational expertise, but rather its correctness was derived from accurate elements represented in the higher-level WDA artifact discussed above. This real-world example provides initial evidence of the ability to efficiently generate tailored checklists comparable, if not more robust, than checklists designed by expert teams.

StrA to Organize a Checklist or Sequence Procedures

After ConTA, Strategies Analysis (StrA) narrows the possibilities for action even further. For each control task, there may be different ways to achieve or satisfy the same input-output function. StrA results in a process description of *how* it can be done and rules out particular ways of performing the task (Vicente, 1999).

While Vicente favors the definition that "each strategy represents a different category of processes", the authors observed multiple types of strategies in the StrA, including: Strategies as Category of Procedures, Strategies as an Information Flow Map of Procedures, Strategies as Detailed Procedures, and Strategies as Instantiated Procedures (see Figure 4).

Strategy as a Category of Procedures
This refers to sets of procedures contributing to the strategy's target goal. A number of strategies applied to *protect traffic and prevent contamination* were observed. These strategies were as follows: separation of WAN and LAN traffic via routers (done by network design); separation of BLACK and RED sides (done by installation of encryptors); separation of management and user traffic (done by filling keys); creation of one-time Cryptonets by color for events (done by event manager); or control of a physical port to allow traffic flow (done by event manager).

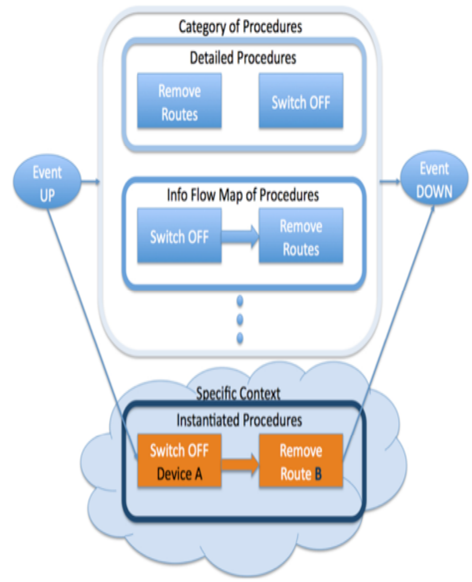

Figure 4 Strategies as Types of Procedures in StrA

Strategy as a Detailed Procedure
This refers to a strategy defined by one or more procedures. Detailed procedures were extracted or referenced from current operating instructions and user guides. Additional, increasingly granular, procedures were derived from the Concept Maps.

Strategy as an Information Flow Map of Procedures
This refers to situations where the sequence or priorities of tasks to be performed are of paramount importance. As a simple example shown in the figure above, post-event shutdown requires activities that must be done in the proper order. According to a senior event manager (the second author) "If these steps are done out of order they create issues and cause reversal in processes. For instance, the ports on the switch need to be turned off before the routes are removed from the cryptographic devices. No routes means no connection to the device you are trying to turn off."

Strategy as an Instance of a Procedure
This refers to a strategy as an instance of a procedure to accomplish a goal in a specific context. For example, the general concept of *managing a device* takes many meanings depending on the features of a particular device. The ISA links were used to organize and instantiate procedures. For example, managing a device

= {Change / Start / Stop / Shutdown / Add / Discover / Select / Delete / Remove} where the procedure is more specifically instantiated by device. If device = encryptor, then Start/Stop/Add/Discover encryptor. If device = Portal, then Add/Select/Remove Portal.

WCA to Identify Artifacts for Training Materials

Worker Competencies Analysis (WCA) adds new constraints pertaining to the limitations and capabilities of human cognition. The Skills, Rules, and Knowledge (SRK) taxonomy can be used to conduct a WCA that provides guidance to the task of training event managers or operator staff.

According to Vicente (1999), to perform WDA, at each level of the taxonomy, one identifies the competencies an ideal worker should exhibit and what presentation form and content is best suited to support the acquisition of those competencies. These competencies can be used to define behavioral objectives to be satisfied by a training program (p. 300). Vicente (1999) points out some limitations of the SRK, namely that it cannot tell us how to design an effective training program. Rather, the utility of the taxonomy is in helping to organize insights, findings, and requirements identified in previous analytical layers of the CWA. In this paper, the observations regarding how these identified training requirements might influence the competencies exhibited by experts and novices were guided by elements of expertise listed in Crandall et al. (2006). Here, competencies are viewed as key cognitive elements that experts possess in quantity or quality greater than novices. One result of this WCA is a set of preliminary recommendations for training materials that can be derived from the identified CWA products.

SRK provides a basis for distinguishing three ways in which workers interpret information in the environment. These ways are signals, signs, and symbols, with each triggering a different level of cognitive control. The levels of control are skilled-based behavior (SBB), rule-based behavior (RBB), and knowledge-based behavior (KBB), respectively. The following describes WCA for RBB as an example. Similar analyses were done for the SBB and KBB, but are omitted here.

At the RBB level, workers interpret the environment via perceptual cues or signs. Signs refer to the states of the world or properties of the environment. Signs activate the RBB, consisting of stored rules that directly specify action and are derived from procedures, experience, or instruction. If a training goal is to help workers deal effectively with task demands, then the salient, sometimes subtle, cues must be known so that workers can rely on their pattern recognition capabilities in real time or offline situations (Vicente, 1999; Rasmussen, 1986).

Vicente (1999) suggested that some of the products produced in previous phases of CWA could be used to support worker recognition of perceptual cues that in turn trigger RBB resulting in desired actions. For example, the following are cues workers should be aware of: (1) the observations cueing shortcuts to control processes, (2) multiple ways of doing (strategies), and (3) procedural constraints, e.g., the order of actions. Speaking in terms of CWA products produced for DMON event management, the team can support training (1) by using the shunts and leaps of the Decision Ladders and derived checklists to illustrate the expert's ability to make shunts, leaps, and shortcuts; (2) by using Information Flow Maps to instruct different strategies; and (3) by structural relationships (e.g., ISA links, Concept Maps, strategies types, means-end) that help learners to know what, when, why, and where a procedure is applied or what other procedures can be used in tandem, e.g., to enhance or confirm their observations establishing situation awareness.

The authors observe that by supporting the acquisition of these cues with CWA products behavioral objectives for a training program that are coherent with the basis of expertise described by Crandall et al. (2006) can be defined. For example, the shunts, leaps, and shortcuts described in (1) above associate with Crandall's perceptual skills; "Experts have developed perceptual skills that enable them to notice subtle cues and patterns and to make fine discriminations that may be invisible to others" (p 135).

Similar associations are made between CWA products corresponding to Rasmussen's three categories of human cognitive controls and Crandall's five cognitive elements of expertise: mental models, perceptual skills, sense of typicality, routines, and declarative knowledge.

CONCLUSION

This report makes the case that the increasing importance and difficulty of simulation, as well as the rising costs of any errors that do occur, puts increasing demands on providing highly reliable simulation support. This challenge can be met in part by the use of rigorous analysis tools such as CWA. CWA has been very effectively used in similar complex, high-risk domains. Further, the authors have shown that CWA offers help in a wide variety of areas, already identified as key opportunity areas for improvement by a recent study of best practices and lessons learned while providing simulation support (DMT O&I, 2009).

This study has performed the first steps in applying CWA to event management for DMON events with much of the effort focused on gathering information from documentation and SME interviews to create core the CWA products. Their use was investigated in three application areas: event management gap analysis across event types, generation of checklists and procedures, and creation of training materials. While the structures and relationships of CWA appeared to offer promise in each of these areas, only in generating checklists and procedures were the authors provided with a real world evaluation opportunity. When the authors compared the CWA-generated checklists with expert-generated checklists, they were judged to be equally good despite being created by a non-expert. This strongly positive result, taken with the more limited, yet still positive, impressions of CWA's suitability encourages the authors to follow this investigation with a more definitive one.

FUTURE RESEARCH

This initial investigation indicates that CWA has the potential to be a useful technique for representing and improving processes and event outcomes in the DMON. To give a feel for the wide range of techniques and uses, the current effort touched on many application areas, and all showed some degree of promise. These areas should be considered in more depth while also pushing ahead to explore the still unexamined elements of CWA. The latter areas for potential investigation are described below.

As part of a research project, DMT O&I (2009) described ways that communication and coordination were improved, and recommended that the life-cycle process for DMON events be analyzed to build more systematically on those earlier improvements. The authors believe CWA may have the potential to make significant contributions to that initial effort and merits further study to that end. CWA co-operation analysis focuses on identifying the allocation of work to individuals or organized teams and could be used as a mechanism to highlight key coordination points and support internal and external coordination necessary for site procedures, event control, event security, and technical operations during the event life cycle. CWA is expected to prove useful in identifying the types and degrees of interaction between different roles and actors during an event (e.g., close cooperation to achieve a function, specific occasion interactions, back-up/alternate relationships, etc.).

This study emphasized producing artifacts to help users execute their tasks. But real life events seldom proceed smoothly, and CWA should also be evaluated for its error-avoiding and troubleshooting potential. Specifically, the ConTA decision ladder may improve the ability to spot and explain unexpected events, where a step on the ladder could link to possible errors and allow for early error prediction and subsequent avoidance. In addition, StrA information flow maps could be used to capture expert troubleshooting strategies and highlight the more error-prone activities, such as manual entry of key data, allocated to humans as candidates for automation.

In the long-term, these application areas and others that arise in future research offer the possibility of putting the entire simulation support enterprise on a firm footing. The CWA view can unify the activities and capture and promulgate expert program knowledge resulting in improved performance and efficiency of all personnel.

ACKNOWLEDGEMENTS

The authors wish to thank Bonnie Danner for her helpful suggestions, generously provided while in the midst of completing her own paper. The authors are also appreciative of the many Specialty Engineering and Operations personnel who provided demos, interviews, expertise and reference documents that were useful in writing this report.

REFERENCES

Burns, C.M, Hajdukiewicz. (2004). *Ecological Interface Design*. Boca Raton, FL: CRC Press LLC

Crandall, B., Klein, G., & Hoffman, R. R. (2006). *Working minds: A practitioner's guide to Cognitive Task Analysis*. Cambridge, MA: The MIT Press

Djahandari K., Archer J., & Danner B. (2009). Cross Domain Solution Challenges Transitioning From Concept to Operations. *Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2009, Paper 9311.*

Distributed Mission Training Operations & Integration (DMT O&I) (2009). *Process Improvement Considerations for the Distributed Mission Operations Network (DMON) Cross-Domain Solution (DCDS) Services*. Orlando, FL: Northrop Grumman Information Systems

Elix, B., Naikar, N (2008). Designing safe and effective future systems: A new approach for modeling decisions in future systems with Cognitive Work Analysis. *Proceedings of the 8th International Symposium of the Australian Aviation Psychology Association*. Sydney, Australia: Australian Aviation Psychology Association.

Jenkins, D.P., Stanton, N.A., Salmon, P.M. and Walker G.H. (2009). *Cognitive Work Analysis: Coping with Complexity*. Burlington, VT: Ashgate Publishing Company

Jenkins, D. P., Stanton, N. A., Walker, G. H., Salmon, P. M, & Young, M. S. (2008). Applying cognitive work analysis to the design of rapidly reconfigurable interfaces in complex networks*. Theoretical Issues in Ergonomics Science.* 9(4) 273-295.

Gawande, A. (2007). *The Checklist – If something so simple can transform intensive care, what else can it do?* Annals of Medicine: The New Yorker. Retrieved June 13, 2010, from http://www.newyorker.com/reporting/2007/12/10/071210fa_fact_gawande

Marsden C., Aldinger M. & Leppard B. (2009). Toward Interoperability between Test and Training Enabling Architecture (TENA) and Distributed Interactive Simulation (DIS) Training Architectures. *Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2009, Paper T-9473.*

Means, C. D., & Burns, K. (2005). Analyzing Decisions and Characterizing Information in C2 Systems. *Proceedings of the 10th International Command and Control Research and Technology Symposium*. Retrieved June 13, 2010 from http://mentalmodels.mitre.org/Contents/CCRTS%20PR%2003-08-05.pdf

Rasmussen, J. (1986). *Information Processing and Human-Machine Interaction: An approach to cognitive engineering*. New York: North-Holland.

Roth, E. M. (2008). Uncovering the Requirements of Cognitive Work. *Human Factors*, Vol. 50, No. 3, June 2008, pp. 475-480.

Sanderson, P. (2003). Cognitive Work Analysis across the system life cycle: Achievement, challenges, and prospects in aviation. In P. Pfister & G. Edkins (Eds.), *Aviation Resource Management (Vol 3).* Aldershot: UK Ashgate.

St-Cyr, O., & Kilgore, R. (2008). A Five-Phase CWA for Air Traffic Control: Example from a TRACON Microworld. *Proceedings of the Human Factors and Ergonomics Society 52nd Annual Meeting*, pp. 272-276. New York, NY: USA.

Vicente, K. J. (1999). *Cognitive Work Analysis: Toward Safe, Productive, and Healthy Computer based Work*. Mahwah, NJ: Lawrence Erlbaum & Associates.