TRAINING ENVIRONMENT SUPPORT SYSTEM (TESS)

PHASE I FINAL REPORT

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14. ABSTRACT
During this Phase I effort, a conceptual design for the Training Environment Support System (TESS) was developed. TESS is designed to help the space community keep pace with rapidly changing satellite operations by (1) adding support applications used in operations to training facilities and (2) providing training support tools for instructors and trainees. TESS will consist of cloned versions of the terrestrial weather, space weather, scheduling, and messaging applications used in the operations center. Training support tools will provide static and real-time guidance and explanation to trainees and will help instructors develop and manage scenarios and monitor trainee performance.

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EXECUTIVE SUMMARY

INTRODUCTION

The current Department of Defense (DoD) emphasis placed on the advancement of space technology and capabilities has produced an accelerated rate of change within the space operations community. Along with the accelerated enhancement of capabilities come numerous task performance challenges for the space operator who must maintain proficiency despite continual change and increasing complexity. Because space operators are facing these challenges and because their proficiency is critical, a training system was designed to help the training of satellite operators – operators working with the Space-Based Infrared System (SBIRS), in particular – keep pace with the operational environment. This report describes the design phase of an effort to enhance SBIRS training for satellite systems crews by (1) increasing the fidelity of SBIRS simulation training environments through the addition of critical space operations center support applications and (2) providing instructors and trainees with training support tools.

APPROACH

A training requirements analysis was performed to identify skills and knowledge that should be targeted by the training system to be developed. Skill and knowledge training requirements were identified based on guidance from SBIRS job performance requirements lists (JPRLs) and subject matter experts (SMEs). This analysis also identified challenging design issues that relate to developing a training system that can be used in an integrated manner with existing training systems, and to using technology and training strategies optimally to support the identified training requirements within a simulation-based training facility. A conceptual design of a training system was developed to target the identified skill and knowledge areas and to address the identified design issues. This design will be improved and refined through iteratively storyboarding it and seeking SME feedback.

PHASE I CONCEPTUAL DESIGN

During this Phase I research and design effort, a conceptual design for a training system called the Training Environment Support System (TESS) was developed. TESS is designed to help the space community keep pace with rapidly changing operations by (1) adding applications that are used to support SOC operations to SBIRS training facilities and (2) providing training support tools for instructors and trainees. More specifically, TESS will consist of cloned versions of the terrestrial weather, space weather, scheduling, and messaging applications used in the SOC. Further, the TESS design specifies a number of training support tools. These tools support scenario development, execution, and management, help instructors monitor trainee performance, and help instructors provide individualized attention to trainees during training exercises.

FUTURE WORK

Future work will involve working with space operations training personnel to iteratively refine the functionality and user interface design of TESS, and then to iteratively implement the training system design specifications. A significant portion of this effort will involve assessing the skills and knowledge associated with each of the support applications contained within TESS, and developing knowledge-based training content (e.g., scenarios, agent feedback, and MEL content) that targets their acquisition.

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INTRODUCTION

Transformation in Space Operations

In the current threat environment, in which military action is often constrained by cultural and population factors, and in which threats are often characterized by small signatures, short durations, and unpredictability, space has emerged as a dominant and essential contributor to military operations and global situational awareness. Space systems and capabilities represent key objectives and enabling technologies for each of the six Global Vigilance, Reach and Power (i.e., Global Engagement) core competencies that the Air Force has identified as key to military dominance in the post cold war threat environment. In particular, ensuring that critical information gets to warfighters quickly and on demand is fundamental to attaining every one of the six competencies and to success in the post cold war threat environment.

To achieve this fundamental information capability, the military is increasingly looking to space. Space systems are becoming vital conduits and collectors of information. Space systems are providing global communications, precision navigation, weather, warnings, and intelligence, surveillance, and reconnaissance (ISR) data to military leaders, planners, operators, and weapons systems in near real-time and, more recently, in real time. The criticality of this data and the importance of receiving it quickly cannot be over-emphasized. Accordingly, the advancement and transformation of space systems and operations has become a top priority, viewed as integral to achieving the Global Engagement core competencies.

Development of the Space-Based Infrared System (SBIRS) of satellites is an example of the transition the space community is undergoing as the Air Force looks to the space community and space technologies to help it achieve its Global Engagement vision. Using SBIRS technology, space personnel will contribute to military operations in ways never before possible. However, its introduction, along with the myriad of other changes facing the space community, mean that space personnel must adapt in a number of ways – that they must learn to process increasing amounts of information, perform new tasks, and increasingly support the operational community and understand the larger and more complex picture within which they are operating. It is critical that training keep pace with these changes and prepare personnel for the specific types of demands they will face.

The criticality of skilled task performance, and therefore of effective training, is evidenced by the potential consequences of error. In the realm of satellite operations, a single mistake or slow response can be extremely costly, resulting in a significant reduction in a satellite's lifespan or in the loss of a satellite, which can cost more than $1.5 billion. Even the temporary loss of a satellite is extremely serious and will only become more so as our dependence on space technology grows. For example, such a loss can shut down large sections of the national and world economy. Insight into this potential for disruption was gained in May of 1998 when service to more than 80% of the United States' approximately 45 million pagers was interrupted for more than 24 hrs due to a malfunction of the Hughes/ PanAmSat Galaxy IV satellite (Gittlen, 1998). In March 1999, the GE-3 telecommunications satellite, which serviced most of North America, suffered an anomaly causing widespread disruption of television and radio services, including the CNN network, Public Broadcasting Service, and Associated Press (CNN, 12 March 1999).

Satellite anomalies and outages can similarly impact military operations in significant ways. The reliance of military operations on near real-time and, in some cases, real-time information is growing, especially as the military moves toward its goal of sensor-to-shooter information delivery. This increasing dependence can be seen in the considerable role played by space systems during the relatively recent war in the Balkans. Space systems provided battle damage assessment, making possible a high ops tempo and a rapid retargeting/replanning cycle; they provided weather forecasting for planning; the Multi-Source Tactical System in bomber cockpits displayed space-derived intelligence that allowed bombers to be retargeted en route and to be used in the close air support (CAS) of ground activity; they provided the global positioning system (GPS) needed for all-weather attacks around the clock and for synchronizing datalinks; and they provided an extensive global communications network (Amrine, 2000).

The work of space personnel is thus becoming increasingly critical to military operations. The costs of the space systems they manage are growing, and the cost of losing communications with any given satellite for even a short period of time is growing. Accordingly, while efforts are made to improve the robustness of advanced satellite technology, parallel efforts must be made to improve the training of space personnel. Ensuring the proficiency of space personnel during this period of rapid transformation is essential.

Training in Space Operations: Keeping Pace with Change

A 2002 article in *Air & Space Power Chronicles* notes that although Air Force Space Command (AFSPC) has a well-structured and generally effective training program, an evaluation of incident data from the 50th Space Wing (50 SW) at Schriever AFB suggests a need for improvements (Gottschalk & Gilchrist, 2002). Incidents evaluated were those that led to a satellite outage or nonoperational period. It was found that 38 of a total of 60 mishaps occurring during a five-year period (1997-2001) were caused by "operator error requiring retraining". More specific causes included inattention to detail, incorrect procedures, and lack of checklist discipline.

These incidents, combined with the potential gravity of their repercussions, clearly indicate that there is room for improving training in space operations. Furthermore, significant attention should be paid to training whenever operations undergo major change. At a basic level, such change necessitates the development of training curriculum and materials, competency measures, training facilities, and much more. However, the increasing complexity of space systems and of the operations environment in which space personnel work calls for more than updating basic training resources. It demands the provision of training resources that are suited to preparing space operations personnel for the complex, dynamic, information rich, and workload intensive environment in which warfighters are increasingly required to work.

SBIRS is a prime example of new space technology that demands these types of enhanced training resources. SBIRS is being developed and implemented across a number of years and likewise, SBIRS training resources are being developed gradually and upgraded in parallel. These training resources will need to take into account the changing work environment of satellite personnel. To do so, they may need to undergo dramatic changes to meet new training objectives.

Possibly as result of this phased development of SBIRS training facilities, SBIRS personnel are faced with what many consider a training resource deficiency. Specifically, SBIRS simulation training facilities exclude certain system applications that are used by operators in the satellite operations center (SOC). As a primary example, SBIRS simulation-based training facilities lack certain important applications that operators use in the SOC. Consequently, procedures often must be skipped or pantomimed by trainees. These excluded applications are

basically support applications that operators use in addition to the core set of crew workstations, and include the following:

- Space weather information application
- The New Tactical Forecast System (N-TFS) for terrestrial weather
- Electronic Scheduling Dissemination (ESD)
- The Defense Message System (DMS)

APPROACH

To address the afore-mentioned shortcomings of SBIRS simulation training facilities, a training system that will augment and enhance training provided using those facilities was designed. The objectives of this design are twofold: to allow operators to obtain training on the use of space operations support applications that are currently absent from SBIRS training facilities, and to provide instructors and trainees with training support tools that will enhance the acquisition of trainee expertise.

Training Requirements Analysis

To develop the training system design, a training requirements analysis was conducted. It was clear that training requirements associated with the absent support applications listed above were not being adequately met. However, it was important to determine exactly what types of skills and knowledge associated with each system would need to be targeted by a training system, and to what proficiency level. This information was provided largely by the SBIRS job performance requirements lists (JPRLs). These lists specified that SBIRS operators should be proficient in a number of skill and knowledge areas that were associated specifically with the use of an absent support applications. For example, the following skill and knowledge areas are specified in the SBIRS JPRLs:

- Respond to Severe Weather/Natural Disaster Notifications
- Identify AFSCN Equipment
- Perform AFSCN Configuration Actions
- Respond to AFSCN Malfunction
- Perform Non-Routine AFSCN Scheduling
- Perform Operational Reporting (reports of relevance to SBIRS systems personnel include SOR, OPSCAP, and MIR reports)
- Perform Electromagnetic Interference (EMI) Procedures (to include submission of EMI report)
- Identify Orbital Mechanics/Space Weather
- Respond to Severe Weather/Natural Disaster Notifications within 10 min
- Submit SOR within 2 hrs of initiation of hardcopy reporting and within 15 min for an L&PI generation when no voice communications with missile C2 agency exist
- Perform Non-Routine AFSCN Scheduling within 5 min of receipt of anomalous information

Thus, a number of SBIRS job performance job performance requirements (JPRs) are associated with use of the absent support applications. In addition to reducing the quality of training, this mismatch between job requirements and training resources can potentially create a serious staffing shortage if it delays the mission ready (MR) certification of needed personnel. Furthermore, personnel do not become as proficient at performing tasks in the absence of

associated training resources as they would otherwise. Without the absent support applications, SBIRS training facilities do not support acquisition of certain basic job requirements and, by implication, do not prepare trainees to perform their jobs as proficiently as they could.

The training requirements analysis additionally included interviews with subject matter experts (SMEs). SMEs emphasized that training facilities need to support the requirement that simulation-based training facilities mirror the operations center. This parallelism makes it possible for personnel to practice complete procedures from start to finish and develop task performance routines that span across multiple systems. As a result, they are able to perform those procedures and routines during real world operations without utilizing significant cognitive resources. In other words, complex procedures become *automatized* or *proceduralized*, and more cognitive resources are available for dealing with other aspects of the task environment. This allows the operator to devote cognitive resources to the many other tasks they have to perform.

As part of the training requirements analysis, survey data were obtained from satellite operations SMEs. These data suggested that SBIRS simulation-based training would benefit from support tools that help instructors:

- detect trainee errors,
- provide trainees with one-on-one attention and guidance, and
- tailor or select scenarios to better meet the training needs of various groups of trainees

In addition to basing the training system design on the results of the training requirements analysis, the training environment and the ways in which the training system could be used within it were considered. There are three major challenges associated with the training environment that the training system design must address. The first of these is the technology currently used to run and store exercise scenarios. The training system will need to be able to run in a synchronized manner with existing training suite workstations during simulation training exercises. The second challenge is related to the first and involves designing TESS so that it is consistent with the ways in which instructors conduct training. For example, it has to support instructors in the development and execution of scenarios that are consistent with the scenarios currently used in SBIRS simulation training facilities. The third challenge has to do with limitations on the ways in which training can be presented during real-time simulation exercises. For example, real time expert advice, context-specific explanation, and feedback associated with error detection were all identified as useful training strategies, but each must be implemented it in a way that does not interfere with time-pressured task performance.

To meet these challenges and address all identified design considerations adequately, the initial training system design, described below, will be subjected to additional design iterations based on feedback from SBIRS training personnel and technical staff. Feedback will be obtained on multiple iterations of this design and subsequently on iterative versions of the functional training system once the implementation stage of development is reached. Our goals in these iterative feedback sessions are primarily to:

- educate SMEs about the approach and technology we are utilizing so they can better evaluate the system and make informed suggestions and
- obtain SME feedback about iterative versions of the training system design.

Other means of meeting these challenges and addressing considerations adequately involve the appropriate and informed use of technology. For example, speech synthesis technology has evolved sufficiently to be considered as a means of providing situation-specific explanation aurally without distracting trainees from tasks that involve processing primarily visual information. In addition, agent technology will be used to support the real-time detection of

errors and evaluation of context in order to provide a variety of context-specific support. This technology is described in the section below.

TESS Cognitive Agents

The training system design features cognitive agents developed using CHI Systems' cognitive agent development toolkit, iGEN (Zachary, Ryder, & Hicinbothom, 1998). The role of iGEN cognitive agents within the TESS conceptual design is to provide performance tracking, real time feedback, and situated support capabilities. iGEN provides both a cognitive architecture for building the agents, known as COGNET, and an execution engine, known as BATON, that allows the agents to interact with users and the external environment in real time. In effect, iGEN is used to transform a cognitive representation of task performance into an executable agent. Thus, it is especially appropriate for developing agents that must track or emulate cognitive task performance. In addition, COGNET is well suited to supporting the elicitation and representation of SME domain knowledge and expertise, and will be used for this purpose during the development of the TESS cognitive agents.

The cognitive architecture and modeling framework embodied by the iGEN approach to agent development is influenced principally by the work of cognitive scientist Alan Newell (e.g., Card, Moran, and Newell, 1983; Newell, 1990). In its simplest form, Newell's Unified Theory of Cognition breaks human information processing into three parallel macro-level mechanisms -- perception, cognition, and motor activity – and attempts to characterize them in terms of general principles derived from years of cognitive science research. Consistent with Newell's theory, iGEN is used to represent perception, decision-making, and action and link them within a common architecture defined by cognitive principles about how information is stored, retrieved, and used, and how these processes are affected by human resource limitations.

iGEN consists of three primary components:

Theoretical framework – COGNET; a model of human information processing architecture, derived from multiple component theories, and a set of theoretically-derived principles of operation

Description language – CEL, the COGNET execution language; a formal way of representing domain-specific knowledge in terms of the COGNET information processing architecture and principles of operation

Behavioral/Cognitive simulation tools – BATON; an executable cognitive architecture associated with a larger set of graphical tools that support the authoring, editing, testing, and debugging of cognitive agents using CEL.

The iGEN perceptual mechanism receives information from the outside world, translates it into symbolic information and, via perceptual demons, and stores it in a local information store (i.e., a blackboard representation of memory) that is accessed by both the perceptual and cognitive mechanisms. iGEN cognitive processes manipulate the information on the blackboard, using existing procedural knowledge and metacognitive controls embodied in the task models (i.e., tasks are represented as sets of procedures organized into goal hierarchies). The tasks can modify the blackboard as part of their reasoning processes, and can also invoke actions that are passed back to the external environment/outside world.

The COGNET architecture within iGEN includes mechanisms that support metacognitive activities such as prioritizing and attention/task switching. These mechanisms, or metacognitive controls, include context-sensitive triggering conditions and priority formulas that influence the order in which cognitive tasks are executed and the ways in which concurrently 'triggered' tasks are executed. In addition, the COGNET architecture specifies a metacognitive blackboard where knowledge about the status of ongoing activities is maintained. iGEN thus supports the representation of situated goal and attention shifting in complex, multi-task performance

situations. Consequently, iGEN agents behave in a much more flexible, non-deterministic way than task network models, in which the flow of tasks must be predetermined.

iGEN has been commercially available for more than four years, was used in-house for a number of years prior, and has been described as comparable with other leading cognitive architectures developed for building agents for use in complex domains (e.g., Pew & Mavor, 1998). This cognitive agent technology has been used to develop instructional agents that support simulation-based training in the domains of anti-air warfare, ground tactical air control, ship control/piloting, and uninhabited aerial vehicle control (e.g., EBS, 2000; Ryder et al., 2000; Ryder, Scolaro & Stokes, 2001; Zachary, et al., 1998), and to develop synthetic teammates that support the simulation-based training of naval air wing teams (e.g., Zachary et al., 2001). In the course of developing this training system, we propose to reuse major components of our existing iGEN and BATON software. This strategy will allow for a reduced software development cost, direct leveraging off many years of research and development into building executable cognitive agents, and a reduced overall risk in the software development effort.

RESULTS: PHASE I CONCEPTUAL DESIGN

In this section, we describe the initial design of the training system we are developing to augment and enhance simulation-based training for SBIRS personnel. This system, called the Training Environment Support System, or TESS, has the primary objectives of providing personnel with:

- the opportunity to perform tasks during training in the same way they would perform them during real world operations;
- opportunities to learn how to interact with support systems and use their information in a training environment rather than on the job; and
- experience responding to alerts and warnings generated by those support systems.

TESS is intended to augment and enhance SBIRS simulation-based training by adding clones of SOC support applications to SBIRS training facilities, and by providing trainees and instructors with training support tools and resources. The training application will emulate support applications that are currently absent from SBIRS training facilities – the DMS, N-TFS, ESD, and space weather support applications – and will feature training support tools. The instructor application will feature instructor support tools including training scenario development, monitoring, and management tools.

The TESS training application will be installed on a single PC within each training facility, and this PC will be networked with the system on which the TESS instructor application resides. This latter system will either be the same system currently used to manage training or it will be an adjacent networked system. Alternatively, it may be necessary to recreate all scenarios for use by the TESS application alone, and TESS would supersede the existing training management software.

TESS additionally will be integrated with training suite workstations. This will allow TESS to detect and react to changes in the simulation environment, such as the occurrence of a satellite anomaly, and it will allow TESS to adapt to track and respond to the progression of the exercise scenarios. As described in more detail below, a performance support toolkit called ADEPT (Agent-Based Decision Enabling and Performance Tracking) that is being developed by CHI Systems for use on SBIRS SOC workstations will be integrated with TESS to facilitate this linkage with the training suite workstations.

The TESS Training Application

The TESS training application is envisioned as a multi-use application. Thus, the application can be used in *basic application mode* to provide trainees with high fidelity versions of the SOC applications and thereby a more complete operational context (see Figure 1). Alternatively, a user can toggle to the *training support mode*. In the training support mode, the cloned applications are reduced to one-third of the display in order to provide trainees with a comprehensive training support environment (see Figure 2).
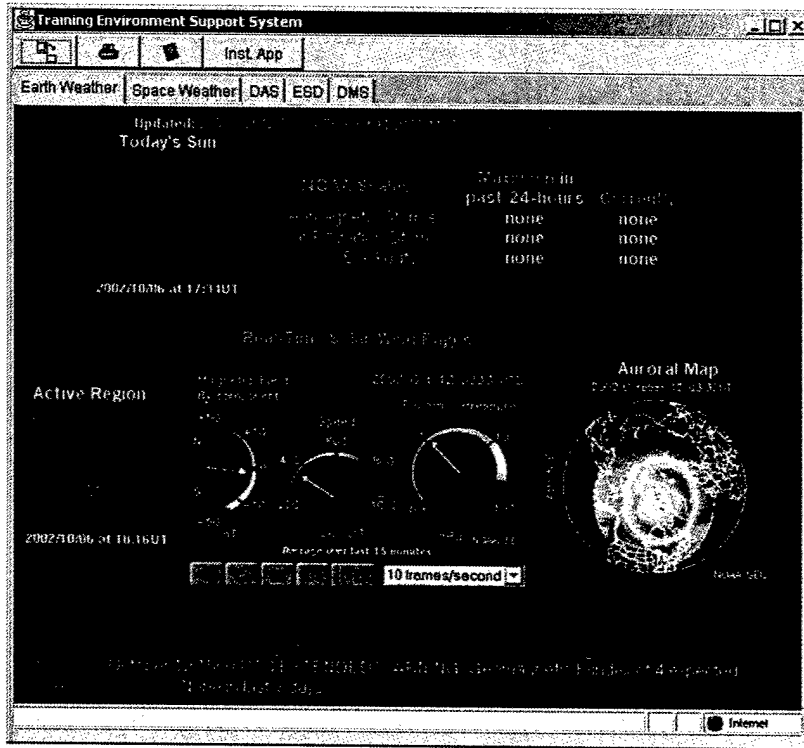

Figure 1. The TESS training application in the basic application mode.

This latter training support mode is intended to expedite the development of proficiency with the SOC support applications contained within TESS. It is also designed to help trainees acquire a 'bigger picture' understanding of when and how to use the cloned support applications, including an awareness of the sometimes subtle relationships among the applications (e.g., a space weather alert may necessitate a schedule change request due to the loss of an asset caused by a geomagnetic anomaly).
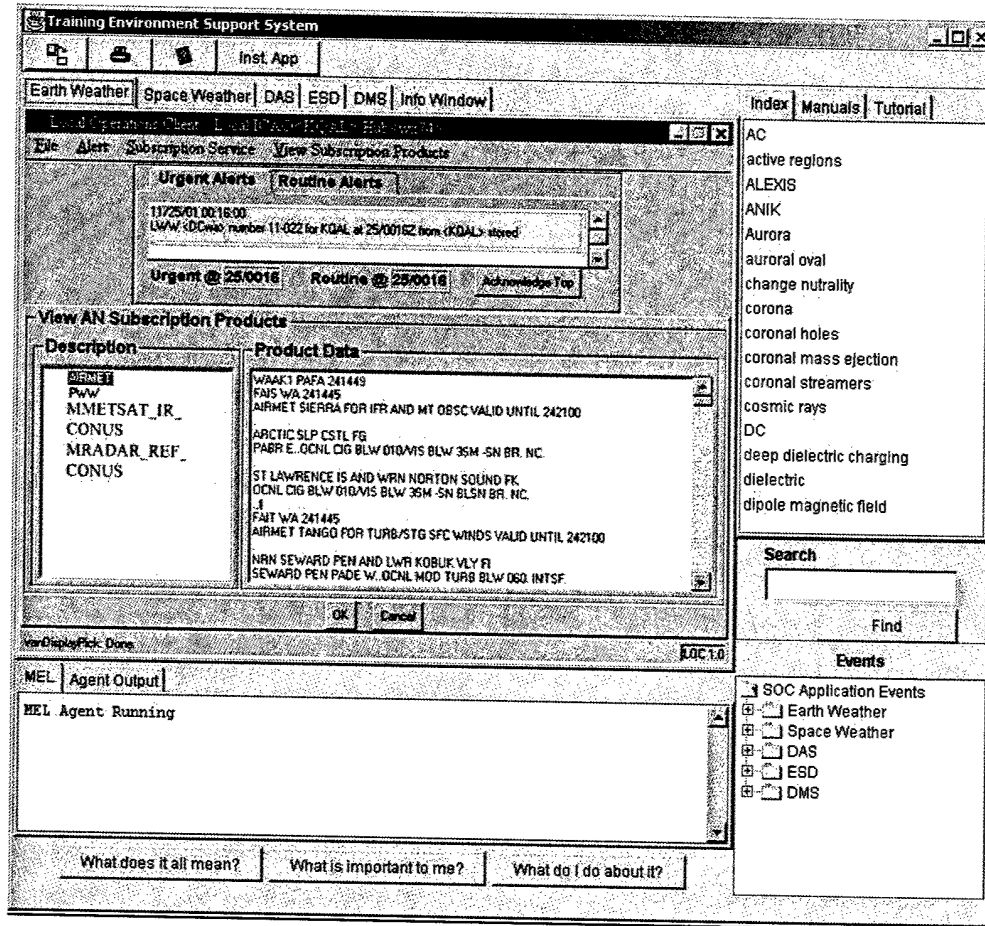
Figure 2. The TESS training application in the training support mode.

TESS trainee support tools and resources available to trainees when TESS is used in the training support mode will include the following:

- *TESS cognitive agent* – the TESS cognitive agent will track and assess trainee performance.

- *TESS cognitive agent output* – trainees will be given real time feedback on their performance as well as context-sensitive explanations and guidance.

- *Managed Exploratory Learning (MEL)* – TESS will, via the TESS cognitive agent, provide expert mentoring and guidance that is tailored to the current situation within an ongoing training exercise. Guidance will change based on whichever clone application is active.

- *Adaptive Decision Enabling and Performance Tracking (ADEPT) decision support tools* – ADEPT is a decision support toolset CHI Systems, Inc. is developing for satellite operators to use in the SOC as part of a Phase II SBIR effort. Reusing the ADEPT application in training facilities by integrating it with TESS will give trainees access to the ADEPT tools, including the:

  o *AWE tool* – trainees can access this tool to view a prioritized list of alerts, warnings, and events (AWEs). Among other things, AWE codes are defined, time limits on time critical AWEs are given, and course of action recommendations are provided.

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- o *Messaging tool* – this tool will allow instructors to give trainees individualized attention and guidance.
- o *Satellite position viewing tool* – this visualization tool provides trainees with a 3-D view of satellite locations relative to the sun, earth, moon, penumbrae, and umbrae, and facilitates understanding orbital mechanics.
- *Self-directed training tool* – when TESS is used in standalone mode, trainees can choose from a categorized list of training events that are specific to the TESS clone applications and train using TESS in the absence of an instructor or when personnel are not available to support a full training exercise.

The TESS Instructor Application

The TESS instructor application will be used to give instructors tools and resources to help them manage training sessions. The TESS instructor application (see Figure 3) features five primary modes of use – automated, manual, scenario editor, analysis, and help. It is designed to provide varying levels of automated control over the execution of a training session, and additionally offers manual control for situations in which automated control is not desired.
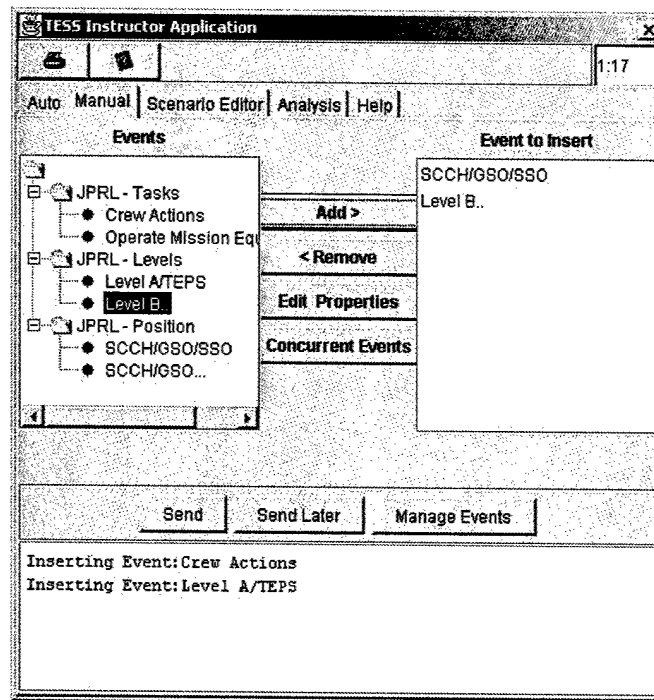

Figure 3. The TESS instructor application.

The proposed set of TESS instructor support tools provided within this application are listed below.

- Scenario management tools, including:
  - *Automated scenario controls* – instructors will be able to select and launch predefined scenarios from a menu. Each scenario will be associated with a script that may be edited and printed.
  - *Scenario development controls* – instructors will use these controls to organize multiple training events into a single training scenario and script. These controls will include a scenario development filter that will allow instructors to view and select from training events that are associated with a particular training objective. Example objectives include various JPRs, skills such as proactivity, crew coordination, and 'comm' discipline, and proficiency using various applications.
  - *Manual event insertion controls* – instructors will be able to insert events into the training environment one at a time instead of using scenario controls to present a predefined series of events.
  - *Event editing controls* – these controls allow instructors to tailor selected events with respect to, for example, severity, satellite system affected, ground system affected, start time, and duration.
- *Training session viewer* – this tool allows instructors to view time-stamped interactions between the trainee and the TESS clone applications during scenario execution, as observed by a TESS cognitive agent. The tool additionally features the detection and report of trainee errors by a cognitive agent.
- *Messaging tool* – this tool, made available via the ADEPT toolkit mentioned above, will allow instructors to give trainees individualized attention and guidance.
- *Performance evaluation capabilities* – instructors will have the ability to specify performance measures to be collected for a given event using the event editing controls. These measures will be collected using the TESS cognitive agents and the results will be entered into a database and subsequently accessed by the TESS instructor application that instructors will use to develop and print training summary reports for training exercise participants.

FUTURE WORK

Space operations are rapidly transforming, and these changes pose a constant challenge to training effectiveness. It is especially challenging to adapt training to fundamental changes in the complexity, stress, dynamicism, and degrees of freedom in the operations environment. Adapting to such changes in a domain in which operator proficiency is vital calls for the development of training and training systems that take advantage of advanced technologies and training strategies that were developed to optimally support performance in complex and dynamic operational environments.

The design effort described in this report involves the utilization of training strategies and technologies that are particularly applicable to simulation-based training to not only meet basic training needs, but to also facilitate the acquisition of expertise. For example, training strategies include scaffolding (e.g., via agent-based feedback and MEL) and real-time mentoring (via MEL). Technology being utilized to these ends includes agent-based technology, which will be used to track trainee performance in the fast-paced simulation environment. In addition, the use of synthesized speech to convey real-time advice and feedback will be evaluated based on feedback received on the TESS demonstration.

Future work will involve working with space operations training personnel to iteratively refine the functionality and user interface design of TESS, and then to iteratively develop the training