Abstract

This paper describes the work-centered design of a system to be used by satellite systems operators and the decision support provided. The United States Air Force (USAF) satellite domain is dynamic, stressful, and cognitively demanding. In this paper, we focus on the specific ways in which ADEPT provides decision and performance support to satellite operators, as well as the benefits of providing such support – improved accuracy, faster task performance times, and greater opportunity for on-the-job learning.

Keywords: decision support, performance support, satellite systems, work-centered design, information comprehension, task performance.

1 Introduction

The Adaptive Decision Enabling and Proficiency Toolkit (ADEPT) was designed using a work-centered design approach with the intention of enhancing a pre-existing satellite ground system. The initial motivation for developing ADEPT came from the significant changes operators are expected to encounter in the coming months. The space community is undergoing significant transition as the U.S. Air Force looks to space technology to help it achieve many of its envisioned Global Engagement capabilities, which led to the creation of the next generation of satellite technology: the Space-Based Infrared System (SBIRS) and the Space Tracking and Surveillance System (STSS). The major components of SBIRS are being introduced incrementally. Once complete, SBIRS will include satellites in geostationary earth orbit (GEO) and highly elliptical orbit (HEO), and will be complemented by the STSS – a constellation of more than 20...
satellites in low earth orbit (LEO). Currently, the SBIRS ground segment is operational and is being used to manage GEO satellites. Over the next few years, the GEO and HEO SBIRS satellites, and the STSS constellation will be launched, accompanied by many changes in satellite capabilities and in the way satellite operations are conducted.

With the help of SBIRS and STSS technology, space personnel will be able to contribute to military operations in ways never before possible. However, the introduction of these satellites also presents a number of challenges for space personnel. For example, satellite operators will be required to manage larger numbers of satellites and process larger amounts of information under increased time pressure. In addition, the efficiency and accuracy of satellite operator performance, which was once considered critical due primarily to the cost of satellite systems, will become much more critical due to the dependency of the operational military community on the rapidly evolving satellite capabilities. For example, satellites are increasingly used by the military to support tactical communications, warfighter situation awareness, intelligence gathering, event detection, and sensor-to-shooter information delivery.

SBIRS and STSS personnel will be facing challenges such as those mentioned above without the advantage of any notable advances in the systems they use to manage and interact with satellites. That is, although satellite technologies will be significantly advanced within the SBIRS and STSS programs, the associated ground systems are based on legacy ground system technologies and designs (Lockheed Martin Space Systems Company [1]). Many legacy ground systems were designed without a full appreciation for the ways in which users perform their work, the challenging aspects of that work, or human cognitive capabilities and limitations. Critically, they were not developed with knowledge of the specific work SBIRS and STSS personnel would be performing.

Many of these aforementioned changes were introduced when the SBIRS ground segment became operational. However, operators will likely face additional changes that may include substantial workload increases when the SBIRS HEO and STSS satellites are launched. Despite the possibility of further change, ADEPT was purposefully designed to support operators primarily in their current work environment, although with an eye to the future. This design decision was based on the logic that problematic characteristics of the current operator workstations will become increasingly likely to impair performance as workload and work complexity increase, and that improving upon them will help operators cope with future work conditions.

2 Performance and decision support

2.1 Design process and findings

It is frequently the case that systems and user interfaces are defined with a focus on individual system functions, and not on how the functions would work together to support a user’s workflow, i.e., to support users as they work. As
noted by Zachary and Bell [2], “Since the system is there to facilitate human work...it should be organized around the work that the person is trying to accomplish (p.1):” it should be work-centered. When users perform demanding and dynamic tasks on systems that are not designed in a work-centered way, the cognitive resources available for task performance are reduced by the demanding information processing and integration tasks. Users may be inefficient in using the system to achieve various task performance goals if the system was not designed to facilitate the conduct of those task performance procedures, and users may have to perform time-consuming information searches that are not supported by the system.

The ADEPT user interface design centers on the ways tasks are performed, and organizes information and resources in functional ways that are adapted to the specific task and situation. Additionally, ADEPT supports work by providing users with a high-level view of the systems they manage, consistent with the tenets of Ecological Interface Design (EID) (Vicente [3]; Vicente and Rasmussen [4]). This high-level view provides users with a real time representation of the satellite systems they manage.

To support the design phase of the project, a domain analysis was conducted that involved several visits to Buckley Air Force Base (BAFB) and Vandenberg Air Force Base (VAFB) to collect data. In addition, one subject matter expert (SME) was interviewed extensively using unstructured interviews to collect data as well as to obtain feedback. As the ADEPT design evolved, iterative storyboards were developed and used to obtain user feedback regarding system design and functionality from our primary SME as well as potential users at VAFB.

During data collection, as well as during the design process, one critical task and multiple common tasks were identified as candidates for performance and decision support. The critical task identified involving responding to satellite and ground system alerts – the SBIRS and STSS satellite systems crews investigate alerts, warnings, and events (AWEs) that appear on their displays to determine if they possibly represent a real problem. If a crewmember determines that an AWE is indicative of a real problem, the crewmember must, based on standard operating procedures, either ‘safe’ the satellite or inform satellite systems engineers of the current status of the satellite. Then the satellite systems engineers troubleshoot the problem and develop a course of action. In response to ground system alerts, operators can perform quick fixes, or otherwise switch to a back-up system until the primary system is fixed. Common tasks identified include:

- Perform routine satellite commanding, e.g. to recondition batteries during eclipse season or to safe a satellite component
- Monitor ground systems for problems; ensure quality and continuous flow of satellite and communications data
- Detect and respond to (bypass or fix) ground equipment failures
- Monitor satellites’ states of health by regularly checking a set of critical system parameters, or *measurands*, which represent the current value of a satellite component or system (see Table 1 for examples)
Investigate and monitor satellite and ground system warnings and events, and bring to the attention of engineers as appropriate

Maintain logs of events and activities

ADEPT was designed to support satellite operators in all the identified – both critical and common. Following a domain analysis and unstructured interviews with a SME, inefficiencies were identified in the following areas:

- Crew communication – not supported technologically. Crews often shout to communicate
- Dependency on paper-based resources – logging, procedure documents, command plans, etc. all still paper-based
- Means by which satellite systems data is represented – data is in measurand form, which consists of a string of alphanumerics
- Organization of satellite systems and other operational data – e.g., information is accessed by drilling down through a hierarchical menu structure, and information necessary for anomaly resolution is located in notebooks at the back of the operations center, etc.

ADEPT consists of five primary support tools, accessed via tabs on the user interface, in addition to a number of support features that are present within all of the primary support tools. The five support tools, or tabs, of ADEPT were designed so that the above inefficiencies may be addressed, and so that the tasks and decisions of the satellite operators may be easier to perform and less cognitively demanding. The AWE Tab presents Alerts, Warnings, and Events and all relevant information as well as information pertinent to the particular measurand about which the AWE is occurring. The Messaging Tab facilitates crew communication with a prioritized instant-messenger type tool as well as “canned” or commonly-used messages. The Satellite View Tab is a pictorial view of the universe and gives the satellites’ positions relative to bodies such as the sun, the moon, the earth, and other satellites. The Logging Tab allows the satellite systems operators to not only electronically log the daily activities and the status of the different vehicles, but also to share these electronic logs real-time so that the necessary information reaches the necessary crew members. Finally, the EDocs Tab is an online resource library that databases crew Temporary Procedures (TPs), Command Plans, and operational manuals, among other things.

To demonstrate the ways in which ADEPT supports the work of satellite operators, an example situation will be described. Specifically in the example, satellite operators are working in a stressful, dynamic, and extremely complex domain. They must make decisions regarding an anomaly’s criticality based on knowledge and information resources, often within very strict time constraints. One example of such an anomaly is an alert for a satellite’s sun shutter being out-of-limits. The user must first decide if the sun shutter is stuck open or closed—a very important decision. If the sun shutter is stuck closed, the anomaly is still critical, but not as critical as if the sun shutter were stuck open. The sun shutter protects a sensitive satellite component from being exposed to the sun’s potentially lethal rays when that particular component is spatially positioned so that it is exposed to the sun. A sun shutter stuck closed is not
desirable, obviously, as it could block the satellite component from completing its mission, but a sun shutter stuck open could potentially cripple the satellite. If a sun shutter is stuck open, then there is a very small window of time during which the operator may ‘safe’ the satellite before any damage is caused. This window of opportunity may also obviously be affected by which direction the satellite is facing and, more specifically, where it is spatially. The operator must decide, based on information resources, as well as the satellite’s current alert and position, what the best course of action would be. As previously mentioned, support tools have been added to aid the operator throughout the decision process: measurand labels to help identify the anomaly; checklists, command plans, and procedures resources to help determine possible courses of action; a Satellite Viewer to help the operators determine the spatial position and criticality of the anomaly; a messaging function to notify the proper crewmembers quickly and effectively of the situation.

2.2 Types of support provided

Based on the identified inefficiencies, the goal was to design ADEPT so that a high level of support could be given to the satellite systems operators. For example, tools were needed to facilitate crewmember communication, assist electronic logging of activities, and provide an electronic document library, for example. Two of the performance support tools, the previously introduced Satellite Viewer as well as an alphanumeric explanation function, are described below. Also described is the context for learning and decision support which ADEPT includes.

Table 1: Example measurands.

<table>
<thead>
<tr>
<th>Measurand</th>
<th>Component Represented</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALFQM</td>
<td>Mainframe Frequency</td>
</tr>
<tr>
<td>CCS1SOH</td>
<td>CCS1 Subsystem Health</td>
</tr>
<tr>
<td>ADPCAV</td>
<td>EDE-A Power Converter Voltage</td>
</tr>
<tr>
<td>ADPCBV</td>
<td>EDE-B Power Converter Voltage</td>
</tr>
<tr>
<td>TCHTRA</td>
<td>Thermal Control Heater A</td>
</tr>
</tbody>
</table>

2.2.1 Explanation

Persistent use of alphanumerics in this domain becomes a hindrance to the user as it is not typically immediately clear as to what they represent to the satellite system. Alphanumerics are generally an inadequate means of representing complex information, such as that in the satellite domain. In this domain, one subset of alphanumerics is the measurands, while a second set of alphanumerics used in this domain are command mnemonics. Though many of the satellite measurands have recurring symbology that can aid the satellite operator in discerning its meaning (e.g., an A or B would be present to represent side A or B of a satellite – see Table 1 for examples), many measurands have very little resemblance to the names of the systems and components they are representing.
This presents the operator with the difficult information processing task of discerning which satellite system or component the given measurand represents. One of the functions included in ADEPT helps to alleviate the cognitive demands caused by frequent alphanumerics. Specifically, measurands can be “moused over” to give the satellite operator the full name of the represented component.

2.2.2 Visualization

Often, as in the given examples, tasks that satellite systems operators must perform are contingent upon the particular position of a satellite in relation to other heavenly bodies, knowledge of orbital mechanics, and other spatially-oriented concepts. Research has shown that spatial information is best understood when represented graphically or pictorially (e.g., Bell and Johnson [5]; Kosslyn et al. [6]). The EID approach to display design also advocates high level representations of a domain as a means of providing operators with an externalized mental model (e.g., Vicente [3]). As operators described difficulty visualizing a satellite’s orbital position, it became apparent that a visualization tool would be beneficial in this context. A tendency for less experienced operators to be unaware of the onset of various orbital events was another consideration, particularly because an incoming AWE’s level of criticality sometimes depends on the spatial positioning of the satellite (e.g., the fault could occur but be non-critical because of the satellite’s spatial positioning, or the level of criticality could escalate drastically due to the satellite’s proximity to the sun, etc.). Therefore, the Satellite Viewer in ADEPT provides the user with a ‘God’s-eye view’ of the universe, including satellites, the sun, the moon, the earth, and other heavenly bodies. The satellite operator may also overlay on the view relational geometry, such as the Solar Aspect Angle (SAA) or the Sun Azimuth Angle--pieces of information used to make a number of important decisions (For example, the criticality of certain anomalies is based on a satellite’s SAA, and the course of action may be contingent upon the satellite’s SAA).

Another benefit of the ADEPT Satellite Viewer is operator interest in the functionality. SME response to the Satellite Viewer has been positive and enthusiastic, especially because it provides the operator with the opportunity to explore the ‘universe’ as well as the various relationships between satellites and heavenly bodies. One feature of the Satellite Viewer that is of particular interest is the time ‘fast-forward’ and ‘rewind’ buttons that will advance the position of the different elements so that they are in accurate position for whatever time the satellite operator chooses, be it two months in the future to locate the next satellite eclipse (a commonly occurring event), or ten years in the past.

2.2.3 Building expertise

Decisions, when made repeatedly and supported with knowledge-rich tools that offer guidance and explanation, allow satellite operators to build expertise in their domain. As Zachary and Ryder [7] note, “decision making is a skill that is learned, and … experts are therefore made not born (p. X).” A relationship is therefore implied between making decisions and learning decisions, and thus a relationship “between decision support and decision training” (Zachary and
Ryder [7]). Based on this theory, designing a tool that provides situated decision and task performance support provides the operator with a good basis for on-the-job training therefore facilitating the transition from neophyte to expert.

Decision-making skill is decomposed into three knowledge/skill components by Zachary and Ryder [7]:

- conceptual knowledge/skill – domain facts and concepts
- procedural knowledge/skill – guidelines and protocols for how to perform the task as well as the ability to perform the task
- relational knowledge/skill – domain-specific decision making skill based on integrated conceptual and procedural knowledge

ADEPT is designed to support operators in each of these three components of knowledge/skill. For example, resources made available by the EDocs tool, such as the operational procedures, checklists, command plans, and temporary procedures support both conceptual knowledge/skill and procedural knowledge/skill, the measurand identifier is an example of conceptual knowledge/skill support, and the Satellite Viewer along with EDocs, for example, is supportive of relational knowledge/skill.

![Image of Satellite Viewer](image.png)

Figure 1: Satellite Viewer.

### 3 Conclusions

The design phase of ADEPT is closing, as is the research that influenced the design, and the next step will be implementation. Though ADEPT is specifically designed for the USAF satellite domain, it can be transitioned to any domain that involves the maintenance and health of mechanical systems. It could be useful in nuclear power systems, oil rigs, and especially remote systems, such as...
commercial satellites, undersea equipment, and other types of space craft. ADEPT was designed so that each of the five main tabs (AWEs, Messaging, Satellite Viewer, Logging, and EDocs) may be pulled apart and used independently, but when grouped with other tabs, becomes a powerful decision support tool.

References


