RE-ENGINEERING THE EUVE PAYLOAD OPERATIONS INFORMATION FLOW PROCESS TO SUPPORT AUTONOMOUS MONITORING OF PAYLOAD TELEMETRY

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ABSTRACT

The UC Berkeley Extreme Ultraviolet Explorer (EUVE) Science Operations Center (ESOC) is developing and implementing knowledge-based software to automate the monitoring of satellite payload telemetry. Formerly, EUVE science payload data were received, archived, interpreted, and responded to during round-the-clock monitoring by human operators. Now, knowledge-based software will support, augment, and supplement human intervention. In response to and as a result of this re-engineering project, the creation, storage, revision, and communication of information (the information flow process) within the ESOC has been redesigned. We review the information flow process within the ESOC before, during, and after the re-engineering of telemetry monitoring. We identify six fundamental challenges we face in modifying the information flow process. (These modifications are necessary because of the shift from continuous human monitoring to a knowledge-based autonomous monitoring system with intermittent human response.) We describe the innovations we have implemented in the ESOC information systems, including innovations in each part of the information flow process for short-term or dynamic information (which changes or updates within a week) as well as for long-term or static information (which is valid for more than a week). We discuss our phased approach to these innovations, in which modifications were made in small increments and the lessons learned at each step were incorporated into subsequent modifications. We analyze some mistakes and present lessons learned from our experience.

KEYWORDS

Extreme Ultraviolet Explorer (EUVE), autonomous telemetry monitoring, communication, documentation, information flow process, information system, innovation, knowledge-based software, lessons learned, one-shift operations, payload, phased approach, re-engineering, satellite operations, telemetry.

1.0 INTRODUCTION

The EUVE project is changing the way it operates the EUVE science payload. Knowledge-based software allows autonomous telemetry monitoring which saves the project money and operates the payload with less human intervention. The long term goal is to have a link from scientist to satellite with no one in between. From the traditional manner of recording and storing information, we have developed an innovative electronic information flow process. Innovations in the information flow process (creation, storage, revision, and display of information) is making it easier for scientists, operators and support staff to exchange information in an environment that has been changed radically with the introduction of autonomous telemetry monitoring and one-shift operations.

2.0 BACKGROUND: THE EXTREME ULTRAVIOLET EXPLORER

2.1 Unexpectedly Successful EUV Astronomy

Members of the Extreme Ultraviolet Explorer (EUVE) project have always questioned widely-held assumptions. UC Berkeley Astronomy Professor Stuart Bowyer, refused to accept the generally accepted opinion (Aller 1959), that extreme ultraviolet (EUV) astronomy was impossible because neutral hydrogen in the interstellar medium (ISM) would "soak up" photons at wavelengths in the EUV band between 912 Å (far ultraviolet) and 100 Å (soft X-rays).

Bowyer and his UC Berkeley EUV astronomy group carried out a sounding-rocket program and placed a crude EUV telescope aboard the 1975 Apollo-Soyuz spacecraft (Lampton et al. 1976). The results were spectacular—four EUV sources were identified: HZ 43, Feige 24, Proxima Centauri, and SS Cygni (Bowyer 1991). This success enabled the Bowyer team to obtain NASA funding for the EUVE project: a low earth orbiting, Explorer-class platform with a set of EUV telescopes.

The EUVE satellite launched on June 7, 1992. During its first six months in orbit, EUVE conducted the all-sky survey, mapping the entire sky at EUV wavelengths. Over 400 bright sources were cataloged. EUVE's deep survey and spectroscopy mission also detected some thousand faint EUV sources in these six months. The current EUVE mission focuses on guest observer spectroscopy with an international body of astrophysicists utilizing the satellite to observe specific targets (Bowyer & Malina 1991; Haisch et al. 1993; Bowyer 1994a; Bowyer 1994b).

2.2 New Directions in Satellite Astronomy Science Operations

While Bowyer developed the new instrumentation, other members of the EUVE project set out to re-cast the way payload science and engineering data were received, archived and processed (Cominsky 1983; Chakrabarti et al. 1988; Chakrabarti et al. 1989).

The goal was to operate the science payload remotely at a university close to scientific researchers, away from NASA control centers. This concept is analogous to the change from "glass room" mainframe computer operations, with dedicated computer professionals carrying out tasks for distant users, to the contemporary practice of using distributed client/server data processing, with users interacting with the main computing resources themselves (Wong et al. 1993; Bevan 1994; Abedini & Malina 1994).

2.3 Reduced NASA Funding Leads to a New EUVE Initiative: Lights Out!

Many NASA projects face a cold future as a result of the changing political climate and diminishing public support for government sponsored space expenditures. In response to NASA Administrator Daniel Goldin's call for "faster, cheaper, better" space projects, the EUVE project redesigned and re-engineered the monitoring of telemetry from the science payload.

A study was commissioned by Dr. Guenter Riegler on July 1, 1993, requesting Dr. Ron Polidan to "determine the feasibility of extending the EUVE mission... [using]... low-cost, innovative technologies." Polidan recommended a three-phase approach that would lead to a "lights-out" operations center with a low operating cost and "full-loop, scientist-to-observatory"' automated, robotic instrument (Morgan & Malina 1995). This change might be seen as analogous to the move from distributed processing to a "workbench" desktop-based supercomputer. Each user has full and complete control of the scientific equipment with no (or little) intervention by others.

Toward implementing this goal, the EUVE team has designed a phased approach with many small steps. The lessons learned from each step are reintegrated into the overall plan. We are also using the EUVE as a testbed for other initiatives (Abedini & Malina 1995; Morgan & Malina 1995; Malina 1994; Lewis et al. 1995). Knowledge-based software will autonomously and automatically, monitor real-time payload operations. Up to now, payload operations have been followed and responded to by human operators on a 24-hour basis (Wong et al. 1994; Wong & Hopkins 1995; Morgan & Malina 1995; Lewis et al. 1995).

3.0 OVERVIEW: EUVE PROJECT DATA AND THE INFORMATION FLOW PROCESS

3.1 Documenting the Information Flow: Three Types of Information

(1) Telemetered data (new data from payload every 90 minutes): The telemetered stream of science and engineering data includes science data, engineering health and safety data, attitude and navigation data. Command loads are uploaded for navigation and to change payload configurations. This is the most important information generated by the EUVE project, however, this paper does not address issues of data telemetry.

(2) Dynamic information valid for less than a week: Spoken and written exchanges relay current information about changing events and conditions such as communications line status, science plans, instrument status, and planned events. Examples include person-to-person contact, telephone conversations, and fax and email messages.

In the ESOC, types of information devices used include white boards, check sheets, daily summaries and various forms for specific situations and the particular circumstances of. each situation. The ESOC daily logbook is used to exchange information between operators about real-time events or time-ordered events such as satellite contacts, the changing state of a hardware or software problem, etc. Science information includes science plans, observation reports, and current observation information, e.g., the guest observer results, etc. Information exchange with NASA includes SCAMA line and telephone conversations, fax and email messages, and daily and weekly reports through the NASA data communications network.

(3) Static Information valid for more than a week: The more stable, written information includes procedures, policies, and directives. For example, written material provides instructions about specific situations as well as for response to recurring situations. A set of approximately 50 ESOC procedures explains and directs actions that ESOC personnel perform in response to specific situations. A collection of ESOC operational directives addresses situations that occur from time to time. Other written material includes the archival use of the daily logbook, a binder of ESOC mail messages that gives direction and relay decisions by management and other groups involved in operations, ground systems, etc.

Static or long-term information exchange with NASA includes the Interface Control Documents, which describe and govern relations between various NASA groups and the UCB EUVE project, as well as memoranda and other written material directing and affecting operations at the UCB ESOC.*

4.0 SIX CHALLENGES FROM MOVE TO ONE-SHIFT OPERATIONS

Twenty-four-hour EUVE mission operations existed before the introduction of autonomous telemetry monitoring. The ESOC began one-shift operations in early 1995. The introduction of autonomous telemetry monitoring and lessons learned from that experience are described in the literature (Morgan & Malina 1995; Lewis et al. 1994; Wong et al. 1994; Wong & Hopkins 1995). The move from three shifts to one staffed shift is discussed in detail by Biroscak et al. (1995, this ITC conference).

We face six fundamental challenges to the way ESOC personnel exchange information, i.e., how the information flow process occurs in the ESOC. Instead of having human operators responding to changes in payload instrument values as presented by Soctools (the previous monitoring system), knowledge-based software monitors the data and responds to perceived anomalies by contacting an off-site human operator. The change from continuous human monitoring to software-initiated responses affects how the operators receive information about the state of the payload in the following ways.

(1) Lack of ready access to relevant information: Prior to one-shift operations, the operator would become aware of slow changes that might lead to a problem. If the problem happened without warning, the operator could look at all the output from the instruments as soon as the problem was seen. The operator had all the relevant information close at hand in the ESOC. After one-shift operations have been implemented, the operator may not be physically present in the ESOC and may not have ready access to the information.

(2) Lack of familiarity with a new problem: An operator awakened at 3 AM by a computer-generated paging system will not be in the same state of awareness as someone who has been up all night watching the telemetry data arrive from the satellite. Also the 1-2 hour time lag it takes to return to the ESOC may allow the problems to worsen.

(3) Discontinuity of information exchange with student operators: After one-shift operations, most operators are students working fewer than 20 hours per week; before one-shift operations, career employees worked at all times. This change affects the amount of information exchanged, because students have academic success as their

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* Please refer to Appendix A for more detail on the information flow process.

highest priority and have less technical ability and experience, while career employees don't have that distraction. Students have less time to interact with the software and less incentive to exchange information clearly and concisely with the rest of the project. Career employees also stay on the project longer, which improves judgement.

(4) New operators' lack of experience: None of the personnel hired now will have had experience with 24-hour operations. Much of the unspoken, generally-known information now shared by personnel will have to be explicitly spelled out for the benefit of these new people.

(5) Operators separated by time: An operator woken up by the software because of a problem at 2 AM responds and then goes back to bed and is sleeping when a day shift person comes into the ESOC at 8 AM. Previously, whoever was in the ESOC at 2 AM would have been there at 8 AM when the shift change occurred. Once again, the communication has to be explicitly recorded to make up for this discontinuity.

(6) Operators separated by distance: Up to now, the shift change occurred between people who were physically present and could exchange information face-to-face. Now, the operator who went home at the end of yesterday's day shift, may be far away from the operator who comes on at the beginning of today's day shift.

5.0 OBJECTIVE OF THE EUVE INFORMATION FLOW RE-ENGINEERING PROJECT

Autonomous telemetry monitoring requires an innovative approach to the information flow process. We are addressing these difficulties so that documentation and communication in the ESOC can support the progress made in autonomous telemetry monitoring. The objective of our innovative response includes four goals:

5.1 Four Goals in our Objective of an Innovative Response

First Goal: Design Appropriate Information Content and Structure.** The content of the information and how the information is structured will affect how well the information is communicated to the user. We have redesigned and reworked the content and its structure to reflect the change in the way the information is most logically communicated. We have added sections to the ESOC procedures that reflect the state of operations in the ESOC. We have changed the content of the white boards and relegated much of that information to other types of output.

** For background material, please see Appendix B: Content and Structure of Text

Second Goal: Design Effective Information Displays. William Horton states, "On-line documentation does not guarantee success or failure. Only good design guarantees success"... "On-line documentation systems are subject to the GITSO principle: Garbage in, Toxic Sludge Out." He further notes, "Displaying paper pages in a smaller grainier, less portable, more glaring device never makes them better and often makes them unreadable. Putting marginal paper documents on line is a sure recipe for failure." (Horton 1994).

To this end, we consider the look and feel of each screen, realizing that moving from paper output to screen display output needs careful redesign. We have made the screen display at 140% magnification to help viewing, and we have limited the amount of information displayed at any time.

Third Goal: Maintain A Single Source while Ensuring Adequate Revision Control. Two difficulties facing every information system are out-of-date material and control of revisions. Our response to these challenges include maintaining a single source of all text and installing a revision control process so that any revision is always date stamped and attributed to the revisor. New revisions are highlighted with change-bars and a hard copy is placed at the operator's workstation.

Fourth Goal: Facilitate User Response Mechanisms. The ease with which a user may respond to a specific display will affect how willing a user is to interact with the system. We use a quick response mechanism that allows the user to type in a text string using a quick command. The input is sent to a file, which is reviewed every day, and changes are made to the documentation as needed. Operators are more willing to make comments and suggestions if they see a quick response from the system.

5.2 The Most Important Innovations in the Information Flow Process

Given these principles for creating on-line information, and reflecting the challenges we face in re-engineering the flow of information as a result of our telemetry monitoring automation effort, we assert that the following criteria must be met in any innovation attempt. Information must be: accurate, clear, concise, unambiguous, and unequivocal. Furthermore, the electronic storage, retrieval, and display of the information must include: maintenance of a consistent content (single source), inherent content control mechanisms (revision control), appropriate formatting to multiple output and displays, and quick and easy user response. These requirements can be met by designing a bullet-proof system of information flow before automating the process of documentation and communication.

6.0 IMPLEMENTING THE FOUR GOALS

Automated message system—We developed a messaging system that allows NASA and others to page appropriate operators and/or leave messages.

Automatic logging—We log realtime passes and use computer-based log files rather than maintain written logs.

Document hyperlinks—Using the capabilities of FrameMaker, hyperlinks were built into the set of ESOC Procedures, so that the indexes and table of contents are linked automatically to the relevant section. A reference to another section has a hyperlink installed for quick cross referencing,

Easily updated variables—Automatic updating of information in the documents is accomplished by using FrameMaker variables, which allow the value to be changed all through the set of procedures. Any changes in hardware configuration or revisions in software can be reflected quickly and easily through the documentation. For instance, all telephone numbers are hyper-linked to a master list.

Transfer to the secure operations network—After editing new revisions of ESOC procedures on the open development network, a read-only file of the entire set of procedures with all the hyperlinks intact is transferred to the secure operations network and the read-only set of procedures are displayed at operator's workstations . by a viewing program from FrameMaker.

Automated user input—We have a one-word command that a user may enter to access a response system. The user then simply types in a text string, which is written to a file. The file, which becomes a collection of user input, is read often and the information is revised appropriately.

Single source and multiple output—Using the FrameMaker capability of "conditional text," multiple output images can be accessed from the same text source. One of these output images is an ASCII "checklist," a short digest of daily duties, printed out every morning.

Other output—includes fully indexed printed paper copies, computer-based facsimile transmissions, text-to-voice over telephone or data line audio, and FrameMaker to HTML formatting for Internet WWW presentation.

Future features—may include automated management input for documentation, hyperlinks within each procedure to reference other documents, automatic variables to revise references to software and hardware changes, and automatic links to NASA/EUVE document changes.

7.0 LESSONS LEARNED—A PHASED APPROACH TO INNOVATION

7.1 Why Process Re-engineering Fails

Susan Mael analyzes how re-engineering projects fail and how they succeed (Mael 1995). Reporting on an article that describes the experience of over 50 consultants (Kiely 1995), Mael lists a number of ways the projects fail and why some succeed.

Failures result from: a manager in charge who doesn't have the clout to ensure success, delegation of the job to a consultant and not following through, a focus solely on cutting costs, and a fear of failure (if enough people think it will fail, it will fail). Success is ensured by: commitment by senior management, realistic expectations, shared vision, and employee involvement.

7.2 The EUVE Experience

Commitment by senior management: The commitment to find new approaches has been a tenet of the EUVE project from the very beginning. EUVE management has always championed innovation. Our experience with one-shift operations is simply one more example. Management formed four teams in support of this project and the information process innovations were always supported.

Realistic expectations: We attempt to maintain realistic expectations by not reaching for a pie-in-the-sky solution to the problem of automated science operations. We use proven off-the-shelf software packages, modified as necessary. We reviewed the capabilities of FrameBuilder, a FrameMaker accessory that creates structured documents. We decided not to buy it because of the high cost vs. capabilities. We did purchase several additional FrameMaker licenses and three FrameViewer licenses.

Shared vision and employee involvement: We encourage participation by everyone affected by the changes, from the initial planning to the eventual implementation. Frequent meetings kept all the users abreast of the changes as they were slowly implemented. User response was encouraged and evaluated at every step. We continue to phase in our changes in small steps to allow for an orderly retreat when problems occur. We changed the information flow process each month, as the autonomous telemetry system was being installed. The whole process of information dissemination kept pace with the changes in telemetry monitoring.

A message on an Internet discussion list suggests: "...the most important component [of successful re-engineering projects] is excellent communication! Whether there is an experience of downsizing or not, it is human nature to be concerned about new change. The implementation team (and the leaders of the organization) have to be forthright in communicating impacts of the change. What are the goals of the implementation? If people will be moved or displaced, get that out early and outline how things will be handled. If no movement is in the offing, still continually communicate this as well. Over communication is not possible in this situation" (Righter 1995).

8.0 SUMMARY: THE INFORMATION FLOW PROCESS AT THE EUVE SOC

The EUVE project has consistently challenged closely held assumptions about the way things ought to be done. From the beginning, when it was believed by most scientists that the EUV was unobservable, through the struggle to establish science operations based at a university, to the present when the funding cutbacks at NASA will force the re-examination of all procedures, the EUVE project has been on the cutting edge of change.

As a result of the autonomous monitoring of satellite payload data, changes must be made in the documentation and communication of information. In the past, it had been easy to document and communicate data and information between the EUVE payload, Explorer Platform, NASA, and the EUVE Science Operations Center. The onset of one-shift operations presents a major challenge. The information flow process will be automated as much as possible to make it clear, concise, consistent, and easily revisable; our experience with the ESOC Procedures has been described.

We describe six challenges faced as a result of one-shift operations. Their effects on the information flow process have been initially identified and responses developed. These responses will be implemented and become permanent as they prove successful in facilitating documentation and communication.

Future plans include automating much of the remaining information flow process. In some of the same ways that the EUVE software End-to-End System automates the reception and archiving of telemetered data (Antia 1993), and like the autonomous monitoring of the data itself using Eworks, the information flow process will be automated using new tools as they become available.

Implementation will be carried out slowly and methodically, with each successful change becoming permanent and the unsuccessful being tossed aside. There is very little literature available describing the experience of others. Newsgroups on the Internet seem to have the most relevant information, but it lacks logical order. The spectacular scientific success of the EUVE satellite, however, gives everyone here at the EUVE project a sense of being part of an important endeavor to which we can all contribute.

NOMENCLATURE

Information systems: the combined set of hardware and software components, text, images and audio, and the formal structure that relates all of the parts to a whole, facilitating rapid citation, storage, revision, and communication of information within a work group.

Information flow process: how information is documented and communicated within the work group.

Documentation: creating, storing, and revising information.

Communication: display, dissemination or exchange of information.

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APPENDIX A. THE INFORMATION FLOW PROCESS

AI. Groups Involved in the Information Flow Process

ESOC personnel (payload controllers and student engineering aides) exchange information with a variety or other people and groups:

- o Other ESOC payload controllers and student engineering aides
- o NASA spacecraft controllers and engineers
- o NASA data and voice communication technicians
- o NASA and EUVE project scientist and science technicians
- o NASA and EUVE administrators and support staff
- o NASA and EUVE ground system hardware and software engineers
- o Tour groups
- o Astronomers and space science engineers via access of the CEA WWW Internet site, and
- o The public and students via access or the CEA WWW Internet site.

A2. The Information Flow Process Up to Now

During the design, development, and fabrication of the instrument payload, a small well-knit group of UC Berkeley EUVE technicians, engineers, scientist, and administrators worked together daily. Communication and documentation developed between people who were familiar with each others' work habits and ways of sharing information with each other.

During the integration or the payload with the platform and subsequent testing, more people, many now from various parts of NASA, came into contact with the UC Berkeley EUVE group. This necessitated more rigorous definitions of form and content of information, but the daily interaction between these groups facilitated the continual improvement of the information exchanging process. Many of the participants traveled between Berkeley and NASA facilities, so these people spent increasing counts or time working together directly.

ln the prelaunch and launch phases, most people traveled at least once between Berkeley, GSFC, and Kennedy Space Center, providing the opportunity for person-to-person communication.

Post-launch, the ESOC's payload controllers and student engineering aides have had the opportunity to interact with each other during 24-hour operations. Again, in-person dialog and conversation have encouraged sharing of data and information between many people here at the ESOC. Examples include shift "changeover," operational meetings, shared work-time, and off-site discussions and conferences.

A3. The Current Information Flow

Some ESOC personnel have moved away from Berkeley and function under contract as consultants to the EUVE project. Voice, fax, and email are used to exchange data and information with them. Most of the contact with NASA personnel now occurs via the SCAMA line (a two-way voice communication facility), regular telephone and group conference conversations, fax communications and email/Internet data communication, or public mail deliveries of written documentation.

Video recordings or various talks and lectures have been produced and can be viewed by new employees who were not present during the original event. Video recordings of the launch in June 1992 are available. In addition, the CEA WWW site may be electronically accessed using ftp, telnet, gopher, and a variety of WWW client browsers including Mosaic, lynx, and Netscape. The EUVE project has generated a large body of scientific and technical literature that may be accessed oyer the Internet at http://www.cea.berkeley.edu.

APPENDIX B. STRUCTURE AND CONTENT OF TEXT

Alison Cawsey discusses eight principles governing the structure and content of [on-line] texts (Cawsey 1992):

(1.) Cohesion (surface level ties): A simple example of cohesion is consistent pronoun use.
(2.) Coherence (conceptual relations): The concepts underlying text should themselves have a natural relationship. For example, in a display of steps to recover from a difficulty, the concept understood with one step should have a relationship to the concept associated with another step. This allows for a natural progression in the recovery procedure.
(3.) Intentionality (the presenter's goal): The presenter (or writer or creator of the document) needs to clearly define the goal and overall purpose in presenting the text.
(4.) Acceptability (the user's goals and attitudes): Simply, it must be kept in mind who is reading the procedure, e.g., a seasoned controller, a new part-time student, or a scientist who is not interested in details.
(5.) Informativity (the user's knowledge): Provide enough information for the person, but not so much as to overwhelm. Give content specific to each group or class of users.
(6.) Situationality (the discourse context): Consider what is happening at the time that the document is being used. Is it an emergency? Is it during a training session?
(7.) Conventionality (look and feel of display): Standardize the form. Present the information in a generally accepted way so that the user understands the form easily. Steps should be in order, etc.
(8.) Extralinguistic Devices: Use diagrams, graphs, and pictures consistently and clearly.

EUVE DOCUMENTATION INNOVATION

Six Challenges from Single Shift

- Ready access to relevant information
- Familiarity with new problems
- Discontinuity of information exchange with student operators
- New operator's lack of experience
- Operators separated by time
- Operators separated by distance

Four Goals of our Innovative Response

- Design Appropriate Information Content and Structure
- Design Effective Information Displays
- Maintain Single Source while ensuring Adequate Revision Control
- Facilitate User Response Mechanisms

Many Innovations Implement the Goals

1. Automatic Messaging System
2. Automatic Logging
3. Document Hyperlinks
4. Easily Updated Variables
5. Secure Operations Network
6. Automated User Input
7. Single Source/Multiple Output
8. Computer-based Fax
9. Text-to-voice
10. Automatic indexed output
11. HTML WWW Output
12. Automatic Variables for hardware/software changes
13. Automatic links to NASA/ EUVE document changes
14. Automatic links to Man pages
15. Telephone numbers updated