SPACECRAFT CREW PROCEDURES FROM PAPER TO COMPUTERS

Michael O'Neal and Meera Manahan
Lockheed Engineering and Sciences Company

Research directed by Marianne Rudisill, Manager, Human Computer Interaction Lab, NASA JSC.

INTRODUCTION

Large volumes of paper are launched with each Space Shuttle mission that contain step-by-step instructions for various activities that are to be performed by the crew during the mission. These instructions include normal operational procedures and malfunction or contingency procedures and are collectively known as the Flight Data File, or FDF. An example of nominal procedures would be those used in the deployment of a satellite from the Space Shuttle; a malfunction procedure would describe actions to be taken if a specific problem developed during the deployment.

A new Flight Data File and associated system is being created for Space Station Freedom. The system will be called the Space Station Flight Data File, or SFDF. NASA has determined that the SFDF will be computer-based rather than paper-based for reasons including the following:

- The long duration of the Space Station program precludes one-time launch of all crew procedures.
- Repeated launch of crew procedure segments is not cost effective since each pound of launch weight costs approximately $20,000.
- Large amounts of manual effort are required to create, edit, and maintain paper-based crew procedures.
- Changes made after crew procedure printing require annotation of each individual copy, a time-consuming and error-prone process.
- The time involved in implementing and delivering approved Space Station crew procedure changes or updates in a paper-based system would be significant, including scheduling of resources on a Space Shuttle flight.

The main components of interest in a Human-Computer Interface (HCI) include the information available on the screen at any given time, how to change the quantity or content of the information present on the screen, how the information is organized, and how the user interacts with the displayed information. Designing an effective HCI is an important step in developing a viable computer-based crew procedure system for reasons including the following:

- An effective HCI will allow faster, more accurate crew interaction with spacecraft computer procedure systems.
- The HCI will facilitate the crew's monitoring of other spacecraft computer systems while performing crew procedures.
- The HCI will allow the crew to easily verify procedure steps performed by the computer system as procedure automation increases.
- A context- and user- sensitive help and annotation system within the HCI will allow the user to rapidly and efficiently access this type of information while performing the procedures.
- The effective HCI will provide rapid, easy access to required supporting information such as procedure reference items.
- The development of a standard HCI across all crew procedures will lessen the amount

of cross-training required for different types of procedures and will thus lessen the amount of errors made during procedures.

The research project described in this paper uses human factors and computer systems knowledge to explore and help guide the design and creation of an effective HCI for computer-based spacecraft crew procedure systems. The research project includes the development of computer-based procedure system HCI prototypes and a test-bed including a complete system for procedure authoring, editing, training, and execution to be used for experiments that measure the effectiveness of HCI alternatives in order to make design recommendations.

CREW PROCEDURE TASKS AND USERS

Many different tasks are required to create and maintain a spacecraft crew procedure system. Procedures must be created by personnel familiar with the tasks in question and by procedure authors and editors. The crew responsible for performing the procedures must be trained in how to use the procedures. Training crew personnel to be familiar with off-nominal procedures is also required so the procedures can be used quickly and effectively if needed during a mission. The main procedure task will be its actual performance during a mission, including assistance and adaptation to changing conditions if necessary. If a procedure is used repeatedly during one or more missions, changes to the procedure may be required to correct inefficiencies or errors, and current versions of such procedures must be maintained and distributed to all appropriate personnel.

Personnel groups responsible for specific crew procedure tasks represent different user groups of the crew procedure system. Procedure authors create the procedures, assuring that they correctly describe the work to be performed and that they conform to a standard procedural format (e.g., FDF or SFDF); they are also involved in scheduling procedures during a mission to create mission plans and crew member short-term plans. Authors may also work with individual payload specialists or experimental scientists. Trainers review the procedures with the crew members who will perform the tasks; comments or problems with procedure details or clarity are reported to procedure authors or editors for correction. Crew members are involved with actual procedure performance, training, and correction or editing if required. Mission control personnel assist in scheduling procedures, working with the crew during the mission, and in monitoring the mission plan and short-term plans. Experimental investigators and payload specialists are involved in creation and execution of those procedures relevant to their experiment or payload. Procedure editors are also responsible for updating and distributing required procedure changes found during training or execution.

An effective computer-based crew procedure system, and an effective HCI to this system, must take into account the full range of tasks and users of the procedure system. In particular, a common interface that can be created by authors and used by trainers, crew members, and mission control personnel will contribute to faster, more accurate interaction with crew procedures.

PROJECT GOALS

The final goal of the current research is to create HCI design guidelines that can be used for spacecraft crew procedures and other computer systems that display procedural information to procedure users. These guidelines should lead to faster, more accurate user interaction with procedural information on a computer.

The first step in the project is a review of available literature on computer presentation of procedural material and the evaluation of the current paper-based FDF procedure system for Space Shuttle. With this information, key issues are identified and their role in the research outlined. Using background information and human factors and computer system knowledge, alternative interfaces are created via prototypes. These prototypes are then evaluated by the various users of crew procedures listed above. Experiments are then performed using different presentation and interaction techniques; these experiments provide specific data on the relative speed and accuracy of procedure tasks using different interfaces. Comments from prototypes and results and conclusions from interface experiments are then compiled into human-computer interface guidelines for presentation and interaction with spacecraft crew procedures.

CREW PROCEDURE ISSUES

There are both advantages and disadvantages of moving from a paper-based to a computer-based crew procedure system. The current research project addresses these issues as they relate to the human-computer interface of the system. Advantages of using a computer will be utilized while disadvantages will be addressed and minimized.

COMPUTER ADVANTAGES

Having a computer system behind the interface to a crew procedure system offers many advantages. By monitoring related onboard systems, the computer system can automatically perform many procedure steps that require simple status verification (e.g., "Check that switch F6 is ON"), thus reducing the time required to perform the procedure. A training mode is now feasible so that the crew member can practice using the procedure in exactly its final form with the exception that system actions are not actually performed; training and execution modes for the same procedure will increase the effectiveness of training. Personal annotation files can be attached to each procedure, thus allowing each crew member to create and refer to individual notes during both training and execution of procedures; these notes will be available whenever and wherever the crew member uses the procedure. The computer-based procedure system can coordinate with other spacecraft computer systems, providing easier transitions to and from other systems. The computer-based help system can adapt to both the user of the procedure and the context in which the procedure is being performed. The amount of detail (i.e., the prompt level) of the procedure can change for different users and situations. Finally, expert systems can be integrated into the procedure system, thus providing a more intelligent interface to crew procedures.

COMPUTER DISADVANTAGES

When procedural information is presented on a computer screen, the context of the information presented typically seems more limited than with a page of paper, although the actual amount of information present on a computer screen may or may not be smaller. There is less context information on where the current screen of information fits into the overall system; in a book, the location of the page in the overall book is an example of available context data. This issue will be addressed in the HCI to the computer-based system by generating and evaluating ideas to provide additional context information (e.g., screen number, screen position in overall outline, etc.).

In a complex computer system such as the on-board Data Management System (DMS) for Space Station *Freedom*, many levels of subsystems are present. The inability to rapidly navigate among the systems and subsystems can be a serious detriment to overall performance. This issue will be addressed in the HCI to the computer-based system by generating and evaluating ideas to provide information on current position within the system hierarchy and to provide tools to rapidly and directly move between subsystems either during or after a computer task.

RESEARCH FOUNDATIONS

Initially, a review of NASA literature on computer presentation of procedural information was completed. Information on work performed at MITRE for the Procedure Formatting System (PFS) project was received and prototypes were viewed (Johns 1987 and 1988, Kelly 1988). Previous research in the Human-Computer Interaction Laboratory (HCIL) of the NASA Johnson Space Center was reviewed, and results from experiments on procedure context and format will be incorporated into the current research project (Desaulniers, Gillan, and Rudisill 1988 and 1989). Coordination is in progress with the Mission Operations Directorate (MOD) at the NASA Johnson Space Center, as described below.

PROJECT STATUS

CURRENT PROJECT PROTOTYPES

Prototype development is in progress for two Space Shuttle experiments. The procedures were selected for prototyping due to their similarity to typical research that will be conducted on Space Station *Freedom* since Space Station procedures are not yet available. The two prototypes will also use different HCI approaches.

The first system is a computer-based prototype of a middeck experiment, Polymer Morphology (PM), that was performed on Space Shuttle mission STS-34. The PM experiment consists of four procedures (set up, sequence initiation, sample check, and stowage) and six procedure reference items (interconnection overview, keystroke definitions, window definitions, notebook, sequences, and worksheets). The prototype is created within the framework of the Space Station basic screen layout being developed by the DMS development team. Included in this prototype is an initial version of an Interface Navigation Tool developed at the HCIL that is currently being reviewed by the DMS team. Initial versions of the six reference items have been created. Development of the interface for the four procedures of the experiment is in progress.

The second system is a computer-based prototype of an expert system for medical experiments to be performed on two upcoming Space Shuttle missions. The system, Principal Investigator in a Box, or [PI], will include an expert system. The motivation for this medical expert system is to provide the capability to perform medical experiments with minimum ground control or support. A separate HCIL research project is in progress to study the interface as it relates to the expert system, and this research will be coordinated with the current research which examines the same interface from the viewpoint of presentation of the procedures. The [PI] interface is being modified for the Space Station basic screen layout and will be evaluated as an alternative HCI design for crew procedures.

CURRENT PROJECT EXPERIMENTS

As discussed above, the current procedures research will include the performance of experiments to gather specific data to support HCI guidelines for computer presentation of procedures. These experiments will begin as specific questions arise from the creation and analysis of HCI prototypes. The experiments will use subjective comments and speed and accuracy measurements to provide data for comparing different HCI alternatives. The experimental test-bed will include a complete system for procedure authoring, editing, training, and execution that will allow HCI alternatives to be easily generated and compared.

COOPERATIVE WORK

In addition to continuing work with the MITRE PFS system, two cooperative projects with the NASA Johnson Space Center Mission Operations Directorate (MOD) are in the planning stages. Research will be performed in the HCIL to assist MOD in creating procedure standards for SFDF. Studies and experiments will be performed to provide human factors input into the standards created. Also, procedure authoring and execution software being developed within MOD will be evaluated from a human factors and HCI perspective.

FUTURE RESEARCH ISSUES

The current research project will continue to explore human factors issues relevant to the interface to electronic spacecraft crew procedures. The effect on the cognitive workload of the procedure users will be examined, with the goal of reducing this workload through automation. The allocation of procedure tasks between the user and the computer system will also be examined. Creating an interface that is adaptable to changing environments will be explored, including the method and user aids available during interruption and resumption of procedures. Research will also be performed on the use of the same computer interface during both training and execution of procedures.

CONCLUSION

Spacecraft crew procedures are increasingly being computerized, as in NASA's Space Station *Freedom* program. The human interface to these computer-based crew procedure systems is an important component, and research into improving the interface will provide faster and more accurate human interaction with the computer. The current research project uses prototypes and experiments to explore and help guide the design and creation of the human-computer interface for spacecraft crew procedure systems such as the Space Station. Prototype and experiment development is currently in progress. Issues relevant to human interaction with procedures will continue to be researched within the HCIL and in cooperation with other crew procedures researchers and developers.

ACKNOWLEDGEMENTS

This research was funded by the National Aeronautics and Space Administration, Office of Aeronautics and Exploration Technology, through contract NAS9-17900 to Lockheed Engineering and Sciences Company. The research was performed at the Johnson Space Center Human-Computer Interaction Laboratory.

REFERENCES

1. *Desaulniers, D. R., Gillan, D. J., and Rudisill, M. R. (1988).* The Effects of Format in Computer-Based Procedure Displays. *NASA Technical Report. Houston, Texas: Lockheed Engineering and Sciences Company.*

2. *Desaulniers, D. R., Gillan, D. J., and Rudisill, M. R. (1989).* The Effects of Context in Computer-Based Procedure Displays. *NASA Technical Report. Houston, Texas: Lockheed Engineering and Sciences Company.*

3. *Desaulniers, D. R., Gillan, D. J., and Rudisill, M. R. (1988).* A Comparison of Flowchart and Prose Formats for the Presentation of Computer-Based Procedural Information. *NASA Technical Report. Houston, Texas: Lockheed Engineering and Sciences Company.*

4. *Johns, G. J. (1987).* Flight Data File for the Space Station, Volume I, Baseline Definition, and Volume II, Baseline Functional Requirements. *(MITRE Report No. MTR10019). Houston, Texas: The MITRE Corporation.*

5. *Johns, G. J. (1988).* Dynamic Display of Crew Procedures for Space Station, Volume I, Baseline Definition, and Volume II, Functional Requirements. *(MITRE Report No. MTR-88D033). McLean, Virginia: The MITRE Corporation.*

6. *Kelly, C. M. (1988).* Conceptual Definition for a Flight Data File Automated Control and Tracking System. *(MITRE Report No. MTR-88D0017). McLean, Virginia: The MITRE Corporation.*