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Operational Aspects of a Spacecraft Planning/Scheduling Expert System

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ABSTRACT

This paper describes various operational aspects of the ERBS-TDRSS Contact Planning System. The ERBS-TDRSS Contact Planning System is an expert system which has been used operationally since June 1987 by the Earth Radiation Budget Satellite (ERBS) Flight Operations Team (FOT) at Goddard Space Flight Center to build weekly schedules of requests for service from the Tracking and Data Relay Satellite System (TDRSS). The ERBS-TDRSS Contact Planning System, which is written entirely in the C language and runs on an IBM PC-AT, reads ERBS orbit prediction data from a 9-track tape and builds a 1-week schedule of requests for TDRSS service in three minutes, with additional time required to print the schedule that has been built. By comparison, the ERBS FOT scheduling expert previously had to spend over six hours per week to do this same task. Several enhancements have been made to the system since it has become operational. In addition, modifications have been made to the knowledge bases of the system to accomodate changing operational scenarios and mission constraints imposed by the TDRSS Network Control Center (NCC). Contributing to the operational success of this planning/scheduling expert system are: (1) the resource window generator which limits search through the orbit data, (2) the custom-built strategies interpreter which applies various strategies to try to schedule primary and alternative events, (3) the custom-built inference engine (TIE1) which automatically checks each event proposed by the strategies interpreter against mission-specific scheduling constraints, (4) the custom-built user interface to the system, and (5) the report generator which produces TDRSS schedule requests in the format required by the NCC.

INTRODUCTION

This paper begins by describing the basic operation of the ERBS-TDRSS Contact Planning System (ERBS-TDRSS CPS). Next, significant enhancements to the ERBS-TDRSS CPS and changes in its operational characteristics are discussed. Finally, some conclusions based on several months of operational experience are presented.

A schematic diagram of the ERBS-TDRSS CPS is shown in Figure 1.

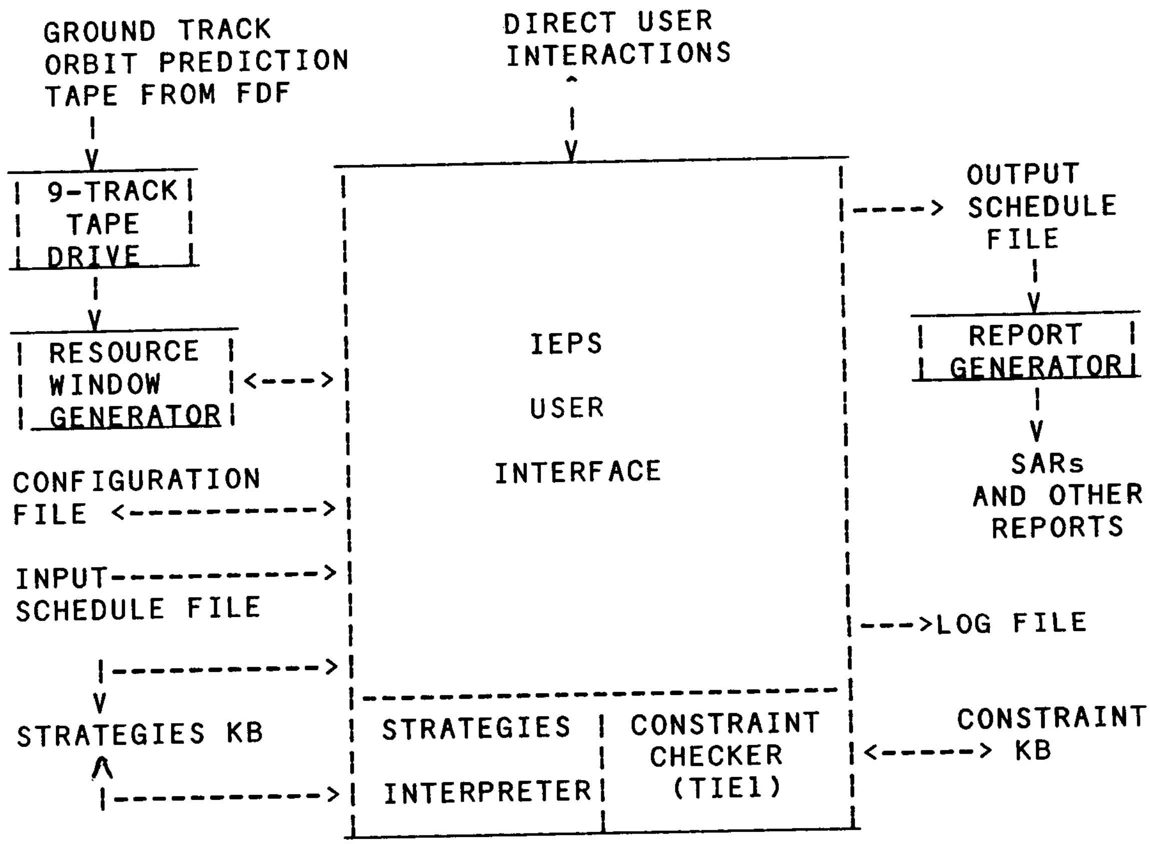

Figure 1: Schematic Diagram of the ERBS-TDRSS Contact Planning System.

In its operation, the ERBS-TDRSS CPS first directs a tape drive to read selected orbital information from a 9-track Ground Track Orbit Prediction data tape obtained from the GSFC Flight Dynamics Facility. Orbital information from the tape is written to the PC that runs the ERBS-TDRSS CPS. This data includes such items as antenna viewing angles and start and stop dates and times for each orbit and daylight period.

Next, resource window generator routines on the PC apply scheduling heuristics to the orbital data to identify resource windows. This process improves overall system efficiency by reducing the amount of data which the strategies interpreter must search through to find TDRSS contact periods.

As the ERBS-TDRSS CPS is run in its automatic scheduling mode, resource window information is used along with system configuration information from a configuration file, scheduling strategies from the strategies KB, and scheduling constraints from the constraint KB to build a 1-week schedule of TDRSS requests. As the strategies interpreter applies primary and alternative strategies to find valid candidates for TDRSS contacts, tentative event information is passed to the constraint checker, the Transportable Inference Engine (TIE1). TIE1 checks this event information against mission-specific scheduling constraints in the constraint KB to determine whether the candidate event should be scheduled. If the primary event strategy is rejected by the constraint checker, the strategies interpreter automatically tries alternative scheduling strategies and passes updated event information back to the constraint checker. This process is repeated for each event until it is scheduled or the strategies list is exhausted.

After a 1-week schedule has been produced in the automatic scheduling mode, the ERBS-TDRSS CPS can be used in the interactive scheduling mode. In this mode, the Interactive Experimenter Planning System (IEPS) user interface provides graphical displays of event timelines and user-friendly editing capabilities.

During interactive scheduling mode operations, the constraint checker is automatically invoked to help the ERBS FOT planner add or delete individual events in accordance with the scheduling constraints in the constraint KB. When there is a scheduling conflict, TIE1 produces a diagnostic message to explain why the event cannot be scheduled. By entering a password, the ERBS FOT planner can override the constraint checker and force the system to schedule the event.

Finally, report generation routines in the ERBS-TDRSS CPS are used to produce reports including: selected data tape records, resource window listings, TDRSS contact request worksheets, and specially formatted Schedule Add Requests (SARs). The SARs that are produced are sent (via a Mission Planning Terminal) to the NCC.

Three papers [1], [2], and [3] that provide additional information about the ERBS-TDRSS Contact Planning System are listed in the reference section.

OPERATIONAL EXPERIENCES

When the ERBS-TDRSS CPS began operating, Ground Track Orbit Prediction data from a 9-track tape was read into an IBM mainframe in the Command Management Facility and then transferred (via a modem) to the PC in the ERBS FOT area. It took about 20 to 30 minutes to transmit the data required for a 1-week schedule. To enhance the ERBS-TDRSS CPS, a tape drive with flexible software was added. This tape drive allowed orbital data for one week to be read from a 9-track tape in less than a minute. In addition, selected orbital data tape records and resource window listings could be quickly verified by the ERBS FOT planner.

After the ERBS-TDRSS CPS operations began, it became evident that the ERBS FOT planner was not comfortable with the multitude of DOS operating system commands required to run the ERBS-TDRSS CPS. To make the control of the ERBS-TDRSS CPS more user friendly, a commercial product was used for adding a high level menu-driven user interface to the system. This interface includes options for: loading the data tape, selecting the scheduling mode (automatic or interactive), entering start dates, selecting antenna service, running the scheduling process, and printing reports. In addition, since the orientation of the spacecraft relative to its direction of travel affects its ability to view TDRSS (and the spacecraft is occasionally "flipped" end-for-end), a menu prompts the ERBS FOT planner at the start of each scheduling session to specify the orientation of the spacecraft and when the spacecraft is scheduled to be flipped.

In response to changing scheduling requirements imposed on the ERBS Flight Operations Team, significant alterations were made to the knowledge bases of the ERBS-TDRSS CPS. For example, several new types of Tape Recorder Dump (TRU Dump) and Stratospheric Aerosol and Gas Experiment (SAGE) events (along with their scheduling strategies and constraints) were added to the knowledge bases. Also, the durations of some tape recorder dump events were changed and separate knowledge bases for scheduling SAGE events during periods of "full-sun" were added. These knowledge base changes provided new scheduling capabilities for the ERBS-TDRSS CPS.

CONCLUSIONS

Although the ERBS-TDRSS CPS has only been operational for several months, significant changes have been made to the system. Some of these changes, such as the addition of the tape drive and the menu system, were made to increase the performance of the system and to make the system more user friendly.

Other changes were made to support new scheduling requirements imposed on the ERBS FOT and resulted in new and different operating capabilities for the system. It is expected that maintenance expertise to support changing scheduling requirements will be required for the life of the mission. For example, when TDRS-West becomes operational, the ERBS-TDRSS CPS will probably have to be modified.

An important aspect of maintaining the ERBS-TDRSS CPS has been the ability to add new scheduling capabilities by editing its knowledge bases. For example, rules and frames in the strategies and constraint knowledge bases were quickly and easily modified to provide capabilities for scheduling several new types of events, each with its own antenna configurations.

Modifications such as these would likely have been much more difficult and time consuming to make in a system with a more conventional software architecture.

Another important factor in maintaining the ERBS-TDRSS CPS was having access to the source code. For example, changes to the source code were required in order to enhance the resource window generator. Most commercial expert system shells do not include access to the source code.

Finally, having a portable, C-based system that runs on conventional hardware, such as IBM PC-ATs under DOS or MC/68020 workstations under UNIX, has been very helpful. Maintenance and development work has been done mainly on the 68020-based workstation utilizing its powerful development environment. The updated source code was then ported to the ERBS-TDRSS CPS PC and recompiled.

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