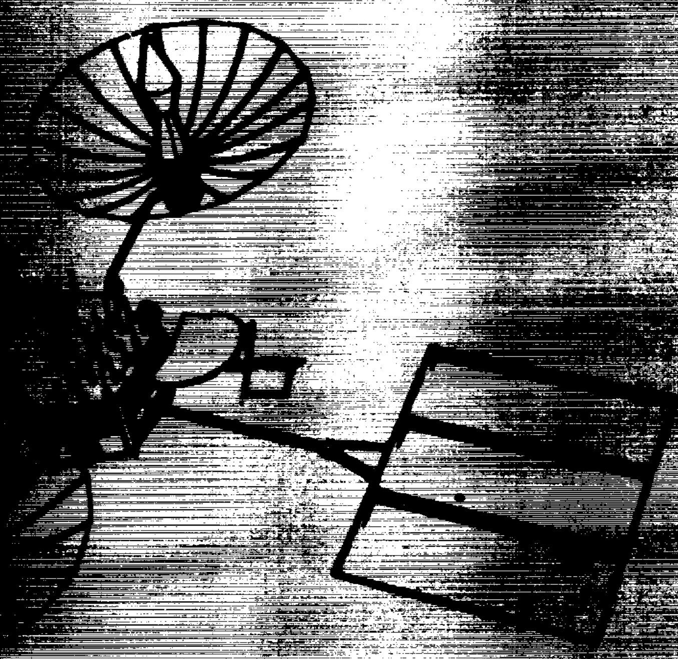
*NASA Conference Publication*

# Network Control Conference on Resource Allocation Concepts and Approaches



*Report of a conference held at Goddard Space Flight Center Greenbelt, Maryland December 1990*

NASA

# Preface

On December 12-13, 1990, about 75 managers, developers and operations experts from NASA and industry met at the Goddard Space Flight Center in an interactive forum to suggest ideas and discuss issues pertaining to the Space Network Control (SNC) environment of the late 1990s. The goals of the SNC Conference on Resource Allocation Concepts and Approaches were to survey existing resource allocation concepts and approaches, to identify solutions applicable to the SN and to identify fruitful avenues of investigation in support of SNC development. Participants heard from experienced speakers on topics related to the three sessions:

1. Concepts for Space Network Resource Allocation

2. SNC and User POCC Human-Computer Interface Concepts

3. Resource Allocation Tools, Technology, and Algorithms

Working group sessions followed each group of presentations to discuss recommendations for the future SNC. This document is a report on the conference, incorporating comments from the presentations and discussion notes.

This conference would not have been possible without contributions from many people. I would like to thank the invited speakers whose presentations provided insight into the Space Network scheduling domain as well as visions for future directions. I also want to thank Dolly Perkins/510, Pepper Hartley/522, Phil Liebrecht/530, Candace Carlisle/532, BJ Hayden/534, Vern Hall/534, and Doug McNulty/STel who contributed as group leaders, and Beth Antonopulos/511, Tom Barlett/514, Eric Richmond/522, Nancy Goodman/522, Lisa Karr/STel, Nadine Happell/STel, Ken Johnson/STel, and Brian Dealy/CSC who were group reporters. Larry Hull and Nancy Goodman, both from Goddard Code 522, were especially helpful in program planning and identifying speakers; Lisa Karr and Doug McNulty of Stanford Telecom made significant contributions to the program planning and preparing the symposium facilities; Nadine Happell, also of Stanford Telecom, reviewed and edited these proceedings; and finally, Bill Watson, the Goddard SNC Program Manager, fully supported the concept and format for the conference.

My sincere thanks goes to all of these individuals, as well as the many participants who contributed openly and freely to the discussion, which is in part reflected in these proceedings.

Karen L. Moe

# Executive Summary

The Space Network Control (SNC) Conference on Resource Allocation Concepts and Approaches provided a beneficial forum for exchanging perspectives and ideas on the Mission Operations and Data Systems Directorate (MO&DSD) planning and scheduling environments. In the late 1990s when the Advanced Tracking and Data Relay Satellite System (ATDRSS) is operational, Space Network (SN) services will be supported and controlled by the SNC. Goals for the SNC are to design a system capable of accommodating changes, to improve user satisfaction, and to improve the use and effectiveness of institutional systems. SNC challenges include dealing with existing operational issues, ones such as minimizing the impact of Shuttle launch slips, and determining the appropriate balance between manual and automated functions. But there are also new challenges, such as supporting demand access and interoperability with international data relay satellite networks.

The conference goals were to survey existing resource allocation concepts and approaches, to identify solutions applicable to the SN, and to identify fruitful avenues of investigation in support of SNC development. About 75 people participated, representing various levels of NASA and industry management, developers, and operations expertise in both the scheduler and service user domains. For two days, participants heard from experienced speakers on topics related to resource allocation concepts, interfaces and technology, and then participated in dynamic working group discussions to elicit recommendations for the future SNC. The following paragraphs condense and summarize several of the key recommendations from the conference.

Management Roles

For the ATDRSS era, providing a concise operations concept with unambiguous guidelines for operations is a top management responsibility. The MO&DSD should establish an intersystems engineering team to address end-to-end planning and scheduling issues. Systems to be included are the SN ground terminals at White Sands New Mexico, ATDRSS, the next generation NASA communications network (NASCOM II), the Customer and Data Operations System (CDOS), and the user Payload Operations Control Centers (POCCs), as well as the SNC. A "help desk" for SN users is also recommended, which would provide advice during mission definition, as well as guidance during mission operations.

The MO&DSD should specify the criteria for success in delivering SN services, determine and measure schedule quality parameters, and provide feedback to users (e.g., compare actual support vs support negotiated in the mission System Interface Requirements Document). Automatic online accounting features should be built into the SNC . Statistics on mission requests, schedule results, resource utilization, and timeliness of schedule generation should be maintained to monitor trends, evaluate operations, and adjust scheduling goals and priorities.

Operations/Automation

Based on experience in the current Network Control Center (NCC), both human interaction and some level of automation are necessary for successful and efficient SNC operations. The recommended approach is to provide automated tools that assist schedulers. Usability is measured by such factors as the time to train operators, and the system's ability to check inputs, to allow "undo" commands, and to provide the operator guidance.

SN schedule generation is seen as a decision support process, but finding the appropriate level of automation is challenging. One recommendation is to design a system that initially allows humans to make decisions, and evolves into a more automated system. Operations personnel would identify routine decisions to delegate to machines as part of the process of designing algorithms to emulate human behavior. Another recommendation is to design a system with automated decision making, but provide full visibility into the entire process, allowing manual override by exception.

The SNC definition should include system engineering approaches, such as modelling the current scheduling process objectives (not necessarily the specific procedures). Human factors analysis methodologies should be employed to identify those functions humans perform best vs functions best performed by machines. Existing industry standards and guidelines for human-computer interfaces should be applied, using tools such as NASA's Transportable Applications Executive, TAE+, to allow rapid prototyping and easy modification of displays. Both NCC and mission scheduler personnel should be involved throughout the SNC life cycle development to evaluate prototypes and verify requirements. Such involvement requires high level management commitments to allow operations personnel the time to participate.

New SNC - User POCC Interface

The current scheduling interface to the user POCC involves a stand-alone terminal dedicated to generating and transmitting specific SN service requests to the NCC. A challenging goal of the SNC is to engineer a new user POCC interface, accommodating a variety of user needs, as well as providing continued support to existing users. Scheduling SN services is a key part of a larger scheduling requirement for the POCC. A hardware independent toolset composed of modular, reusable software components should be provided as an optional scheduling aid, allowing user POCCs to integrate SN scheduling tools with their mission unique systems.

The SN scheduling process should be compatible with user mission goals, but different classes of missions have different schedule drivers. The scheduling interface needs to accommodate both high and low priority users, users who have scheduling flexibility and those who don't, and users with different scheduling timelines. A user scheduling timeline is the most natural time frame for planning and scheduling activities. User timelines can range from minutes for demand access users, to a year or more.

The concept of a flexible request language was discussed as a potential candidate for the user POCC interface. This flexible request approach represents a major change in operations concept. Today the user submits (and resubmits) specific requests and receives a yes/no response. In flexible request scheduling, the user thinks through all service options and codifies flexible service windows in a request language. The SNC scheduling system then has more information to work with in attempting to satisfy flexible requests, increasing the likelihood of success.

Flexible requests identify service resources and the times they are required, how often a service is required, expiration dates of service need, and alternatives if a service isn't available. Flexible requests can be characterized as having:

- two dimensions, flexibility and repeatability;
- three types of flexibility: time, request priority, and resource alternatives;
- specific requests as a special case, where flexibility is 0 and there are no repeats;
- definable dependencies/constraints;
- symbolic definitions which can be referenced by name;
- expressions of simple or complex relationships (a language).

Two key points implied by the flexible requests approach should be noted. First, SNC and the POCCs should have standard access to scheduling data services (e.g., ephemerides, acquisition times) and mission elements (e.g., antenna models, spacecraft day/night calculations). This data is required for expanding and interpreting flexible requests. General scheduling constraints used by many missions should be maintained by MO&DSD and provided as a user service, whereas mission unique constraints should be supplied by the POCC.

Second, incentives for efficient utilization of SN resources and the scheduling process should be provided. A problem in today's scheduling process is the tendency for users to overschedule resources, in anticipation that some requests will be rejected. If user POCCs can be encouraged to specify flexibility in their requests, then the scheduling system can better accommodate their requests, eliminating the need for extensive rescheduling. Incentives are recommended for early submittal of requests, for including flexibility in specifying requests, and for maintaining that flexibility late into the timeline.

A proof of concept for generating schedules, using a prototype flexible request language called the Flexible Envelope Request Notation, has been successfully demonstrated and is discussed in Session 2 of the proceedings.

Prototyping for the SNC

Building rapid prototypes of critical components of the SNC environment was discussed throughout the conference. Recommended prototyping goals are to provide an iterative format involving users (both SNC and POCC operators) in evaluating concepts and generating requirements, to guide decisions regarding levels of automation, to inject innovation, to mitigate risks and capture lessons learned. Further, resulting systems could be provided to the SNC implementing contractor.

Prototyping is seen as a productive approach to answering some of the concerns raised during the conference, particularly regarding the flexible request concept and schedule generation, various operational scenarios (e.g., Shuttle launch slips), and user interface issues. Specific objectives were mentioned in the following areas:

• Flexible Scheduling Requests - determine the balance of flexibility vs complexity, the computing power/speed required to schedule and the accessibility of scheduling information required to interpret flexible requests.

• Nominal Operations Scenario - demonstrate the scheduling process using flexible requests, comparing timeline horizon models, and evaluating request processing/response times and request submittal requirements.

• Rescheduling Scenarios - demonstrate the ability to develop alternative schedules, or wait lists to handle events including of Shuttle launch slips, spacecraft emergencies, targets of opportunity and service demand access needs.

• Fault Management - demonstrate techniques for SN service outage detection and rescheduling.

• Human-Computer Interface - illustrate coding and naming techniques, as well as graphics.

• Scheduling Algorithms - evaluate search algorithms and metrics, scheduling goals and heuristics, and performance issues, especially in regard to the impact of rescheduling.

• Schedule Timeline - evaluate alternative timelines for schedule generation such as the forecast and active periods for NCC scheduling, addressing batch schedule processing with interactive rescheduling vs the continuous incremental scheduling model.

- Schedule Quality - define criteria for evaluation, determine statistics for measuring quality, and evaluate the effect of priority schemes, scheduling goals, and scheduling algorithms on schedule quality and efficiency.

## Conclusions

The SNC Conference on Resource Allocation Concepts and Approaches generated a wealth of ideas for consideration during the SNC definition period. Many of the recommendations are being pursued or investigated further in the various SNC development tasks. A prototyping effort for SNC is underway to address as many of the suggested topics as time and funding will support. An initial testbed is planned to be established by the end of FY91 and will include an SNC scheduling prototype and a user POCC workstation interface. The testbed operations scenario will demonstrate the use of a flexible scheduling request language and operator tools for generating and maintaining an SN schedule. Those involved in the SNC development will continue to seek input and guidance from individuals and institutions involved in SN scheduling.

# Table of Contents

# Section 1—Introduction

The goals for the Space Network Control (SNC) conference were to survey state-of-the-art efforts in planning and scheduling, assess their applicability to the Space Network (SN) domain of the late 1990s, and make the information and ideas raised during presentations and discussions available in proceedings to those responsible for the SNC definition.

## 1.1 Background

By way of background, the Network Control Center (NCC) of today is providing scheduling and technical management functions for the SN, ground network and interfaces to other networks such as the Deep Space Network. But the SN is changing with the Advanced Tracking and Data Relay Satellite (ATDRS) services, a possible mixed fleet of TDRS and ATDRS, the updating of the TDRSS ground terminal and other ground functions (e.g. NASCOM), and interoperability with the international space network community. It is becoming increasingly difficult to maintain the current NCC to meet these new challenges.

Therefore, the goals for the SNC are to create a system architecture capable of accommodating changes in hardware, software, interfaces, and span of control. Also, the SNC program desires to improve the SN user's satisfaction by improving the user interface, accommodating varying levels of user sophistication and need, and increasing the percentage of support requests granted. This is to be accomplished while improving the utilization and effectiveness of SN institutional facilities, including operations and maintenance costs (SNC life cycle costs), as well as system reliability and resource scheduling. A 5% increase in scheduling efficiency may save the cost of an ATDRS over the 15 year program life cycle (a savings of approximately $200-300 M).

## 1.2 SNC Challenges

The scheduling challenges facing SNC include making efficient use of network resources, minimizing the impact of Shuttle scheduling on other users, improving the user POCC interface for SN scheduling, refining the procedures for the scheduling process (e.g. the forecast and active periods), scheduling to avoid RF interferences, and providing better tools for conflict resolution. Some demands of the systems of the late 1990s include managing the transition from today's TDRSS to the ATDRSS and from the NCC to the SNC, scheduling support for the Space Station Freedom, proximity operations (e.g. Shuttle and SSF), international space network interoperability, and the concept of demand access to SN services. The partitioning of functions between human operators and automated systems will be a key SNC issue, as will be the concept of making flexible scheduling requests, sometimes referred to as "generic scheduling".

Recommendations from a recent GSFC study on planning and scheduling lessons learned in the Mission Operations and Data Systems Directorate (MO&DSD) were presented at the conference. Personnel from eight missions and several MO&DSD institutional facilities were interviewed to identify relevant mission characteristics and analyze lessons learned. Key recommendations presented were to develop end-to-end planning and scheduling operations concepts by mission class; to create an organizational infrastructure at the directorate level, supported by a steering committee with project representation, responsible for systems engineering of end-to-end planning and scheduling systems; and to use modeling capabilities and other system engineering tools to ensure that mission design impacts on planning and scheduling systems are understood early in the system life cycle. The study emphasized the need for flexibility in the operation of the Advanced Space Network, other institutional resources, and external (e.g. project) capabilities including operational software and support tools.

## 1.3 Conference Format

The SNC conference was designed to provide a forum for discussing these topics and capturing the highlights for use by SNC designers. Three sessions were defined to focus attention on first the concept and system engineering issues, second on the more visible human-computer interface and end user interface issues, and finally on the technology and tools that are evolving to address resource allocation problems. By surveying space-related literature and by pursuing personal contacts, a series of presentations were selected for the sessions. Each session was followed by a working group discussion. Discussion leaders assisted the smaller (7-9 participant) groups in addressing the session topics, and elicited observations, issues, and questions from the participants. Each group was further assisted by a reporter to help capture the highlights of the discussions for these proceedings. In all sessions, lively discussions ensued and thorough rough notes were generated. Complete copies of the agenda, discussion topics, presentation handouts, and a list of attendees are included in the appendices.

## 1.4 Acronyms

| | |
|---|---|
| AI | Artificial Intelligence |
| ATDRS | Advanced TDRS |
| ATDRSS | ATDRS System |
| BER | Bit Error Rate |
| BFSSE | Best First Search for Schedule Enhancement |
| CHIMES | Computer-Human Interaction ModElS |
| CDOS | Customer Data and Operations System |
| COMS | CDOS Operations Management System |
| COMPASS | COMPuter Aided Scheduling System |
| CPU | Central Processing Unit |
| FERN | Flexible Envelope Request Notation |
| GCM | Ground Control Message |
| GCMR | GCM Request |
| GSFC | Goddard Space Flight Center |
| HCI | Human-Computer Interface |
| HST | Hubble Space Telescope |
| JPL | Jet Propulsion Laboratory |
| LDBP | Long Duration Balloon Project |
| MO&DSD | Mission Operations and Data Systems Directorate (Code 500) |
| NASCOM | NASA Communications System |
| NCC | Network Control Center |
| OMP | Operations Mission Planner |
| ODM | Operations Data Message |
| POCC | Project Operations Control Center |
| PSAT | Predicted Spacecraft Acquisition Times |
| RALPH | Resource Allocation Planning Helper |
| RF | Radio Frequency |
| ROSE | Request Oriented Scheduling Engines |
| RSA | Range Scheduling Aid |
| SAR | Schedule Acquisition Request |
| SIRD | Support Instrumentation Requirements Document |

| | |
|---|---|
| SCAN | Scheduling Concepts, Architectures and Networks |
| SME | Solar Mesospheric Experiment |
| SN | Space Network |
| SNC | Space Network Control |
| SOLSTICE | Solar Stellar Irradiance Comparison Experiment |
| SURPASS | Science User Resource Planning And Scheduling System |
| SSF | Space Station Freedom |
| STGT | Second TDRSS Ground Terminal |
| TAE+ | Transportable Applications Executive Plus |
| TDRS | Tracking and Data Relay Satellite |
| TDRSS | TDRS System |
| TOPEX | Topography Experiment |
| TRUST | TDRSS Resource User SUpport Tool |
| UAV | User Antenna View |
| UPS | User Planning System |
| WSC | White Sands Complex |
| WSGT | White Sands Ground Terminal |

# Section 2—Conference Overview

The following sections provide a brief overview of the material presented in the three conference sessions. Readers are encouraged to refer to the complete conference handouts provided in the Appendix. Several presentations included written papers, also provided in the Appendix. Other reference papers are organized in the bibliography by session. Following presentation highlights for each session is a synopsis of the working group discussions, derived from notes from the seven working groups.

## 2.1 Concepts for Space Network Resource Allocation

The first session was intended to provide a framework for discussing end-to-end concepts for SN scheduling, with many topics being investigated further in later sessions. Papers were selected to reflect systems engineering perspectives, or to suggest considerations for the SNC operations concept.

### 2.1.1 Session 1 Presentation Highlights

<u>Concepts, Requirements and Design Approaches for Building Successful Planning and Scheduling Systems</u> , Rhoda Hornstein, NASA HQ Code OX, and John Willoughby, Information Sciences Inc.

The first briefing provided a programmatic perspective on building planning and scheduling (P&S) systems, which were described as primarily human decision support systems that determine how shared resources will be managed. Their objectives are to make accurate and timely assignments of resources; identify, avoid, and resolve conflicts; provide effective and complementary human-to-computer interfaces and uncomplicated human-to-human interfaces.

The challenge to managers of P&S efforts is to achieve operational effectiveness, by doing the right job efficiently and extensibility, by planning to accommodate change. Doing the right job entails focusing on system engineering to define and build the 'right system' rather than to define and follow the 'right process'. This implies developing competing alternative operations concepts, prototyping, and defining operations effectiveness criteria for acceptance testing. The second challenge, accommodating change, is aided by specifying requirements at a 'class' level by recognizing general case relationships that drive design (e.g., object-oriented design approaches). Other aids are the use of data or rule driven tools, and the development of an evolutionary acquisition strategy wherein layers (rather than segments) of the system are iteratively designed and implemented.

Prototyping is used to provide operations feedback on requirements to support design.

P&S systems are challenging because the product, i.e. the schedule, is difficult to quantify (as it represents acceptable compromises), it is dynamic (what was acceptable many times in the past may no longer be), and it depends on the process used to generate it. The schedule's merit is process, not product dependent. That is, even an inferior solution may be deemed acceptable, if it is known that a number of alternatives were examined, and this solution is seen as the best that can be done. Also, the information flow between requester and provider must be balanced between the frequency of messages and their length and complexity.

Some design recommendations are as follows:

- Design the system as a replanning system since planning is a special case of replanning, and demand access can be accommodated as a special case of planning.

- Design a decision support system and initially allow humans to make all decisions; then delegate routine decisions to machine processing using algorithms which emulate human decision behavior. (Let operations determine what is routine.)

- Pool resources to accommodate requests for any quantity of a shared resource and handle individual resources as a special case of pooled resources.

- Handle general temporal relationships, then accommodate sequence relationships as special cases (predecessor/successor, minimum/maximum delays, etc.).

<u>COMS Planning and Scheduling Concept Assessment,</u> Todd Welden, Computer Sciences Corp.

Study results performed for the Customer Data and Operations System (CDOS) Operations Management System (COMS) were highlighted. Major concepts promoted are flexible scheduling (also called generic scheduling) via a flexible request language, and open access to (non-secure) scheduling information via databases and networks.

The flexible schedule requests approach allows users to symbolically define and reference constraints, request repeatable resource sets, and express complex relationships, flexible time durations, and flexible resource requirements. A major benefit of this approach is efficiency, since more information (flexibility) is supplied to the scheduler, increasing the probability that a request can be satisfied. At the same time this approach supports very specific requests without any flexibility.

A standard, robust, readable, and flexible scheduling request language is recommended for the SNC/user POCC interface. Such a language would allow the standardization of scheduling engines to process requests, and would also be applicable to mission scheduling beyond the SN. In addition to allowing users to specify flexible options for support, it allows the production of schedules which retain the flexibility information, resulting in potentially smaller impacts during rescheduling.

Language features include the capability to add, delete and replace flexible and specific requests, individual request instances (generated from a repeatable generic request), pending requests, and scheduled events. The language can express user defined flexible time intervals (tolerances, windows) and sets (e.g.,spacecraft day), flexible request durations, generic requests which generate multiple events, and preferred and alternate sets of resources. The latter option allows the scheduler to determine which of the pooled resources to assign.

It was recommended that the SNC maintain a database which contains configuration codes, ephemeris, user antenna view data, previously submitted user requests, and time interval sets. The motivation for this recommendation is that SNC is on-line and the missions require the same data needed by SNC. A central repository aids in data consistency and reduced data traffic and redundancy. Standard scheduling information products could be provided in response to user process queries in a standardized format.

An RF Interference Mitigation Methodology with Potential Applications in Scheduling, Y. Wong, GSFC 531, and James Rash, GSFC 531

This presentation recommended that scheduling time constraints calculated using RFI mitigation techniques be an input to the scheduler.

A methodology and a prototype tool were described for determining the separation angles between antennas for any two user spacecrafts to avoid signal interference and to assure BER link margins (reference complete paper in Appendix C). The methodology determines potential interference time intervals for a given spacecraft and suggests that these data be provided to the scheduler as additional constraints. This approach is representative of a class of constraints derived from physical and orbital factors. Other members of this class may also be considered for use in SN scheduling.

Automatic Conflict Resolution Issues , Jeff Wike, TRW

Background information and several considerations for conflict resolution were presented (reference complete paper in Appendix C). The current SN conflict resolution process in the NCC is a verbal interchange between forecast analysts and user POCCs, since security considerations prohibit POCCs from accessing the entire schedule. The NCC scheduler software emphasizes conflict avoidance. A recent analysis indicated that 90% of the conflicts were manually resolved (by alternate link assignments and/or time slips), which indicates that user flexibility exists.

Automatic conflict resolution requires goals to guide schedule generation, and scheduling knowledge. Knowledge is both embedded in the scheduling system (e.g., user capabilities, preferences, SN resource data) and identified by the user POCC in each service request (e.g.,tolerances, alternatives, mission unique constraints). However, it was noted that special circumstances will always exist which require manual conflict resolution (e.g., spacecraft emergencies).

Some organizational goals which affect conflict resolution are priorities, assigned equipment links to specific users, not utilizing spare resources, maximizing use of single resources, leveling of resource utilization across the system, and rewarding cooperation. Potential conflict resolution strategies include priority schemes (varying priorities), shifting a service in time, shrinking service duration, using alternate resources, gapping (i.e., breaking and reestablishing) services, and finally deleting services.

<u>Effects of Locus of Resource Control on Operational Efficiency in Distributed Operations</u>, Amy Geoffroy, Martin Marietta

This presentation examined distributed operations from the science user perspective through hierarchical levels from control centers to SNC and SN facilities, to the spacecraft and finally to the science instrument. Key user scheduling issues are resource coupling (how tightly coupled is the communications service to instrument operations), demands of the mission for specific requests rather than flexible requests, and real time demands.

The question of central vs distributed control was addressed. For decision making, control may be centralized in a distributed network, which eases the scheduling problem. If inter-node interactions allow services to be partitioned into smaller local networks, distributed control is preferred. Distributed control may be required because of security/privacy and authority issues. However, distributed control may compromise flexibility or efficiency. Also, flexible requests, though more efficient to schedule, do pose difficulties in the distributed control of tightly coupled resources.

For centralized control with distributed access, globally available information and globally established priorities are necessary for decision making. Other scheduling approaches recommended for investigation are block resource allocation, cross-scheduler negotiations, and control re-directions.

<u>Resource Allocation Planning Helper - RALPH</u>, David Werntz, JPL

The final paper in the first session discussed the approach and lessons learned from the RALPH system. RALPH was developed to plan the Deep Space Network and became operational in 1987. It generates schedules two years in advance. During the eight week period prior to an encounter and during real time, rescheduling is handled manually.

A key lesson learned, as noted in their paper in the 1990 Goddard Conference on Space Applications of AI (see Bibliography), is that the system initially conceived and requested by users may not be the solution of their problem. The scheduling methodology may change in response to the power of the tool provided.

### 2.1.2 Session 1 Working Group Notes

The following topics were provided to the Session 1 working groups to promote discussion.

Session 1. Concepts for Space Network Resource Allocation

1. Identify the 3 most critical issues for Space Network resource allocation in terms of:

a) Management
b) Operations
c) SN User POCCs
d) System Development

Include a sentence or two, as needed, to explain/clarify each issue.

2. Select at least 3 of the critical issues above and suggest ways of resolving them. Address innovation and risk factors. Identify areas for further study and suggest study approaches.

3. Discuss how resource allocation might be performed for:

a) Rescheduling in the event of a failure to the ATDRSS Ground Terminal.

b) Scheduling of previously allocated resources that unexpectedly become available (e.g., Shuttle launch slips).

4. Discuss the pros and cons of dividing the schedule timeline into forecast (batch) and active (incremental updates) periods. Suggest alternative schedule timeline approaches for SNC consideration.

5. Given that there are different user classes, discuss the pros and cons of subdividing available resources into multiple subnetworks based on user classes and demands for use by each user class.

The first discussion topic was intended to identify critical issues for Space Network (SN) resource allocation in terms of management, operations, SN users, and system development. Suggestions for resolving issues, innovative ideas, and risk factors were solicited, and recommendations are grouped below. A final section groups the questions generated.

### 2.1.2.1 Management

Improve User Understanding of SN Services

A major issue brought out in most groups addressed the need by the SN users to understand SN and SNC capabilities and limitations so that their service expectations are realistic. Users also need to consider the impact of spacecraft design and operations on SN resource availability and utilization. However, they should not need to know the operational details of the SN to use its services, as they do today. Likewise, SNC should demonstrate an understanding of user needs, and that these needs differ by spacecraft class, rather than consider all users to be the same. Furthermore individual users in the POCC, including developers, scientists, and schedulers, have different perspectives and needs.

Many groups endorsed the recommendations made by Toni Robinson in the introductory presentation that the Mission Operations and Data Systems Directorate (MO&DSD) establish a management forum for end-to-end planning and scheduling issues. A key directorate level product would be operational guidelines for intersystem engineering, including an outline of SN objectives and end-to-end operations concepts (such as nominal operations, SN failure contingency, and rescheduling after a Shuttle launch slip). These guidelines would bound MO&DSD obligations levied by the mission Support Instrumentation Requirements Document (SIRD).

Suggested topics for the guidelines, some of which exist in current documents, are technical overviews of the SN (spacecraft, ground terminals and SNC), resource availability profiles and service capabilities, and the flexible request capabilities. User considerations, such as the advantage of being able to use more than two ATDRSs if onboard ATDRS ephemerides are available, could also be discussed.

Finally, MO&DSD should provide a help desk to assist users in developing end-to-end planning and scheduling operations concepts as well as to help in day-to-day problem solving.

SNC Scope

A related suggestion is to explicitly and clearly delineate the SNC control scope, defining end-to-end responsibility and authority. This delineation includes establishing a clear locus of control and functional allocation between POCC users and the SNC. The SNC should not make major modifications to accommodate an individual user's unique needs.

There are also issues to be addressed in SNC's role to existing missions served by today's NCC. Should the SNC be backward compatible to the NCC? Or is it reasonable to require current missions to upgrade their SN interface in 5-7 years?

## SNC Operations Concept and Requirements

High level management approval of a comprehensive scheduling operations concept, encompassing user POCC, SNC, NASCOM II, CDOS and WSGT/STGT, is a necessary prerequisite to developing an end-to-end scheduling system. Management must mediate the tendency for organizations to want exclusive control over their own resources.

Generation of this operations concept must involve operations personnel throughout the SNC system life cycle. A management commitment is needed to make operations personnel sufficiently available to support such non-operations functions. The issue is that there is too much software influence, and too little systems engineering and operational experience involved in current system development decision making. Extensive use of NASA in-house scheduling experience is also recommended.

It is recommended that requirements be developed from the user POCC view, not the SN/SNC developer view. A key issue raised is how to get end users involved in the SNC definition process, primarily the operations concept and requirements. The trend for missions to use distributed systems with remote user capabilities may also have implications on SNC.

Recommendations and investigations affecting the SN operations and policy which require management endorsement include:

- Develop a new standard interface between the SNC and user POCC based on the flexible request scheduling concept.
- Investigate allowing mission priorities to vary over time or by request within pre-specified bounds.
- Investigate using spare SN spacecraft for peak loading periods.

## User POCC Requirements for SN Services

The users POCCs should be giving the SN their service requirements, rather than specifying solutions. A complimentary recommendation is that SN personnel be involved in defining and developing spacecraft communication requirements. For example, one mission had planned on relying entirely on real-time operations for data transfer. The NCC explained the operational complexity and risk involved with this plan. The mission then modified their operations concept to include tape recorders.

### 2.1.2.2 Operations

SN Schedule Quality

Discussions in this area raised many questions. For example, how should schedule quality be determined? What is the criteria for a good schedule? Goals, heuristics, optimization, and user satisfaction (defined here as meeting stated mission objectives and applying principles of priority) are factors to consider.

Schedule Automation

Based on NCC experience, automation of some scheduling functions is crucial to more efficient operations. However the level of detail within constraints that can be captured by automated techniques is a concern. One stated view is that "medium bright" human beings are necessary to successful scheduling systems since some constraints are not conducive to automation (e.g., political decisions). Providing automated tools to assist operations personnel with their jobs is suggested.

Another viewpoint is that the SN scheduling problem is well known and can be modeled by analyzing the NCC. Therefore a fully automated scheduling system, which allows operators full visibility into the entire process and manual overrides by exception, is possible.

The Scheduling Process

There were a number of recommendations regarding the scheduling process. Rescheduling and contingency planning are big issues in today's NCC. It is recommended that planning follow the same process as replanning, not two separate processes. Another suggestion is to integrate all SN facilities (i.e., spacecraft, ground systems and networks) into one SN schedule. Others suggested pre-allocating blocks of services to high priority users, who then return unused resources when their plans are firm.

Interoperability with other networks, including international networks, is a new concern which needs to be considered in the scheduling process.

SNC Accountability

Efficient use, as viewed from both resource utilization and user effectiveness, is a key issue. A trend was noted for low priority users to be more efficient than high priority users. High priority users tend to ensure availability and cover unknown contingencies by overscheduling. One view is that users know a certain percentage of requests will be rejected, so they overschedule. Today Landsat is the only mission charged for SN services, and the only one to delete requests for services no longer planned for use.

SNC should integrate service assurance and accountability with the scheduling process. Accounting statistics should address the number of requests submitted, modified, resubmitted, percent accepted, and compare the results to the SIRD commitments.

#### 2.1.2.3 SN User POCCs

User Accommodation vs Standards

There is a delicate balance between accommodating diverse user needs and providing manageable standard services. It is important to define the standard POCC and SNC interface to accommodate a range of users. A key concern is how the SNC can be more responsive to the variety of users. One approach is to define user categories and a spectrum of standard options available in each category. The SNC must consider how best to accommodate both secure and non-secure users with minimal impact on operational efficiency. The apparent dichotomy between flexible users and those with a need for demand access also needs to be addressed.

The potential exists for the development of common tools shared by SNC and users. Regardless of the source, tools for the user POCC and the SNC need to be compatible, and use the same language.

It is suggested that a conference of a similar format to this one be organized for user POCCs to discuss their requirements for the SNC.

Flexibility and Incentives

The concept of flexible schedule requests is recommended. This concept requires users to define their points of flexibility, and is discussed in detail in session 2. The specific scheduling of today is equivalent to the minimal form of flexible scheduling with tolerance parameters set to zero. A concern was raised regarding the potential for flexible requests to unduly increase the complexity of the scheduling system.

Another concern is the tendency for users, especially new users, to over subscribe resources. Incentives are needed which act to promote efficiency, and to reward cooperation and the use of flexible requests.

Some discussion revolved around how the SNC can be more responsive to low priority users. A free enterprise concept is suggested, where users are allocated points according to their priority, and points are exchanged for resource requests. For example, more specific (less flexible) resource requests cost more points than flexible requests, but utilizing suddenly available resources (e.g., from a Shuttle launch slip) would require very few points. A dynamic priority scheme may be employed to allow low priority users to eventually be scheduled.

Data rates today are fixed to a known set of values, but other standard SN service modes could be defined. The "TDRS wildcard" is an example where users simply request the service mode and the scheduler determines which spacecraft resources to allocate. Will users be willing to accept multiple access services instead of single access? Flexible requests could specify rate and data quality parameters rather than single or multiple access mode. The flexible request approach also implies that standard constraints, such as definitions for time periods (e.g., "Monday afternoon" is anytime from 12:00 to 4:59) or common orbital events (South Atlantic anomaly) are maintained as a service to all users. However, mission unique constraints would be submitted as time intervals in the user's requests.

Information Access and Timing

Authorized users will require easy access to common planning and scheduling information. Information needs and timing of feedback on schedule results (i.e., when users require resource commitments so that other payload operations can be prepared) may vary for different user classes.

User POCCs have different timing drivers based on the science mission and the spacecraft characteristics. The feasibility of varying the SNC scheduling timeline by user or user class should be investigated. Today's NCC forecast/active timeline is restrictive to many users. Reactive scheduling and real-time operations are particularly difficult.

#### 2.1.2.4 System Development

Design Drivers

A major SNC challenge is to design to accommodate change. Modularity emphasizes small, loosely coupled functional implementations rather than traditional system builds of a monolithic system. Modularity also allows for greater adaptability and the potential to "undo" individual automated functions should the operations concept be deficient. Design should be driven by functional performance requirements rather than a detailed specification. Requirements should be determined and confirmed by prototyping and by operations and user feedback throughout the system life cycle. Also, consideration should be given to the testability of the scheduling system requirements.

Recommendations include use of system engineering methodologies which advocate re-use, extensibility, and standardization and which employ software development and delivery environments. One group comments "push systems engineering instead of engineering systems". Finally, the development of the SNC and user POCC interface should be tightly coupled, and the operational compatibility between the systems tested.

Technical Issues

A single architecture for scheduling and rescheduling is recommended rather than a separate system for each. The architecture and information traffic flow for distributed control should be determined. A networked architecture for the SNC is one alternative that has been offered for consideration.

Prototyping is suggested as a means to validate alternative designs and study automation issues. Automatic checking of requested services for compliance with technical scheduling constraints such as RFI mitigation should be considered.

Methodologies

Rapid prototyping utilizing iterative build (design and implement) and evaluation cycles, is highly recommended as a means for users to define requirements and validate operations concepts. The term "spiral prototyping" with user involvement at each cycle is used to convey the desired iterative approach.

Other methods suggested include:

- Modelling operations at a significant level of detail.
- Using a design team approach with members from all elements which could be affected.
- Using an object-oriented design to maximize flexibility (C++ language for prototyping, class libraries, Ada for supporting system evolution).

#### 2.1.2.5 Session 1 Specific Questions

Responses to three additional questions posed to the working groups are summarized below.

Resource Allocation Concepts for Contingency Rescheduling

Several groups commented that the flexible request scheduling approach aids rescheduling, provided flexibility information is maintained and remains valid.

Rescheduling in the event of a failure to the ATDRSS Ground Terminal.

Minimum requirements for anticipated contingencies should be defined during mission planning. One suggested approach for dealing with a ground terminal failure is as follows:

- At time of failure, determine user impacts and criticality.
- Perform reschedule based on current priorities.

- Exploit the potential for automating "minimally disruptive" scheduling techniques.
- If needed, replan entirely after a specific lead time (e.g., replan all events 24 hours after failure).

Scheduler tools, like editors, should be designed to allow easy access to information so that rescheduling may be performed quickly. Disturbance to the overall schedule should be minimized.

Scheduling of previously allocated resources that unexpectedly become available (e.g., Shuttle launch slips).

The ability to take advantage of opportunities to schedule additional resources in this case must be designed into the system from the start. Using a Wait List is recommended. Users can be prepared to execute activities, which were pre-planned for the event of a launch slip. In other words, alternate schedules are developed in parallel to utilize pre-allocated resources. This concept is feasible because state of the art scheduling techniques are very time efficient. Break points in the timeline are needed to effectively return to the primary schedule after the contingency operations are completed.

Schedule Timeline Alternatives

The pros and cons of dividing the schedule timeline into forecast (batch) and active (incremental updates) periods were discussed. Alternative schedule time spans of months, days, and minutes were suggested.

The current 14 day forecast period is considered too long and forces overscheduling. Instead a 4 day forecast period is proposed, and considered a possible change even for the current NCC.

One group stated that some type of forecast and active periods are inherent in any scheduling problem. Batch processing of requests provides more efficient scheduling. Low priority users may favor forecast schedules since it "guarantees" support. However the current scheme discriminates against missions that don't or can't plan in advance, and it is difficult to accommodate late changes.

Another group suggested a more continuous timeline, spanning months instead of days. Users submit requests when it is best suited for them to do so. Therefore there exists a firm schedule in near term, but a softer, sparsely populated schedule in the future. This approach is useful in accommodating surges in service requests. However, at some point prior to execution, everyone must commit to the schedule.

Missions with complex operations may require more lead time to generate payload commands based on a committed schedule. Others may be able to live with schedule uncertainty until very near to execution. Mission factors affect the user's view of the timeline. For example, Hubble Space

Telescope's natural planning cycle for observations is a year, whereas Landsat's window is 16 days (to completely cover the earth).

Other comments include:

- Use a flexible scheduling language and rewarding flexible requesters;
- Penalize resource wasting;
- Negotiate commitments through established guidelines;
- Report to users the likelihood that they will be scheduled; and
- Consider dynamic and multiple priority schemes.

Subnetworks

Participants were asked to discuss the pros and cons of subdividing available resources into multiple subnetworks based on user classes and demands for use by each user class. Dedicated resources (equipment chains) are scheduled today on an informal basis (e.g., one antenna is reserved for Shuttle) and this could be made into a formal operations concept. Advantages of this approach are that subnets may better accommodate users who can't plan in advance, by setting aside a pool of resources for their use. Subnets may also allow easier scaling up for increased services, (e.g., add a new subnet when a new satellite comes on-line). If secure operations were partitioned to one subnet, then non-secure missions could potentially operate in the open.

Some questions are raised concerning how to avoid underutilization of some subnets. Transferring resources between subnets to achieve efficient load distribution and the impact of launch slip rescheduling on users both need study.

## 2.2 SNC and User POCC Human-Computer Interface Concepts

This session focussed on two types of user interface considerations. First human-computer interface issues were discussed from both the SNC and user POCC operators point of view. Next, the system level interface between the SNC and its users, the POCCs, was addressed in the context of a human readable scheduling interface language.

### 2.2.1 Session 2 Presentation Highlights

User Interface Issues in Supporting Human-Computer Integrated Scheduling, Lynn Cooper, JPL

The insights presented are based on experience with JPL's Operations Mission Planner (OMP), an automated scheduling prototype using an iterative refinement approach based on AI technology. The OMP scheduling domain is over-subscribed with large numbers of complex requests. JPL's research centered on minimally disruptive replanning and the use of heuristics to limit the scheduler's search space. (See Bibliography for OMP references.)

The OMP user interface was designed as a developmental, rather than an operational interface. It was used to develop and debug heuristics, to enable developers to assess OMP's progress toward completing a schedule, and to allow others to visualize the OMP multi-phase approach to scheduling (i.e., what actions are being performed and why). By contrast, an operational interface would address how operators use OMP in an operational environment. Operational utilization would require additional heuristics to interact with users, provide feedback on how user actions affect the schedule, and assist users in performing interactive scheduling (providing guidance to the schedule operator).

There are two major considerations in specifying a user interface. The first is the functional distribution between automated functions, which are process oriented (develop, assess, modify schedule), and human functions (identify new heuristics, direct/guide schedule changes, monitor and verify schedule execution, identify problems). The second consideration is the type of user, such as the schedule system operator (who adjusts the process, interprets results of algorithms, modifies/develops new heuristics, analyzes performance statistics) and the schedule end user (who requests activities, sets preferences, defines limits/tolerances).

In OMP the human operator controls the processing with the same degree of authority as the automated control heuristics. User modification to a schedule is considered, but is not necessarily absolute. A dynamic overlay technique allows the user to identify the preferred location of an activity on the schedule timeline, but the scheduler algorithm may move it to resolve a conflict. If the user moves it back to the previous location, the scheduler overlay increases the weight of preference and does not move it again.

Human Factors Issues in the Design of User Interfaces for Planning and Scheduling, Elizabeth Murphy, Computer Technology Assoc.

A NASA survey of planning and scheduling tools and analysis of human factor issues was presented. The study produced design guidelines with illustrative display concepts based on human factors literature. Some of the key issues found in the survey include:

- The visual representation of the schedule to reflect temporal ordering of events
- Evaluation of schedules to compare and select from alternatives, (e.g., histograms showing percent of criteria satisfied)
- Identification of available resources to compare requested vs available resources

- Conflict resolution support, (e.g., highlight conflicts or suppress non-conflicting events). This support is based on analysis of the operator's goals and mental tasks.

Some general recommendations for user interface design are to perform an operations task analysis and focus on the cognitive tasks, to support visualization and direct manipulation of data, and to involve operators in the development process. Detailed recommendations are found in the report referenced in the Bibliography.

A Planning Language for Activity Scheduling, Stuart Weinstein, Loral AeroSys

The Flexible Envelope Request Notation (FERN) discussed in this presentation was developed for NASA scheduling applications. Users generate flexible requests in FERN, which are then submitted to the Request Oriented Scheduling Engine (ROSE) for interpretation. ROSE then generates a schedule timeline of user activities based on FERN requests. The motivating factors for developing a scheduling language were readability, ease of use (e.g., default values need not be entered), and the ability to express options and alternatives all in one request.

The language should be robust, keyword based (not positional) and object oriented (data abstractions with reusable data objects). It must support a variety of user resource requirements and constraints including alternative resource amounts, repetitive requests based on orbital events (vs specific start times), flexible time durations and relaxable constraints. FERN allows information flexibility in resource specification, request duration and repeatability, experiment timing and coordination between activities, alternative activities, and relative importance of each requirement.

FERN requests are hierarchically structured, supported at the top level by generic (or flexible) requests, then activities, and at the lowest level, steps. Generic requests specify the pattern of activity replication, alternative activities, and the rules of request implementation. Each activity describes the sequence of steps which make up that activity, the duration of each step, and activity constraints. Steps define the resources required and any constraints on the step. Other key FERN structures include resource representations (pooled, durable or consumable, variable over time), constraints, and timegraphs (specifying different time periods).

CHIMES: A Tool for HCI Analysis , William Weiland, Computer Technology Assoc.

The Computer-Human Interaction ModElS (CHIMES) methodology and toolset was developed for evaluating existing human-computer interfaces (HCI) and for predicting design impacts and selecting design alternatives for planned interfaces. It assumes a functional hierarchy of mission, function, subfunction, task, and subtask. The system analyzes the demands placed on personnel resources, i.e., cognitive (analytic, verbal), sensory (visual, auditory), and motor attributes.

The CHIMES process starts with a model of the operator's job, and rates HCI demands on the operator (visual, etc.). The tools then evaluate or predict overall operator workload and performance, identify trouble spots (e.g., high or low workload, performance), and recommend improvements. The CHIMES prototype currently evaluates a single alphanumeric display screen (visual and analytic demand). CHIMES includes a sophisticated user-system interface, knowledge bases, display analysis tool, modification advice, and an explanation facility. Future development include graphics and color analysis, and a refinement of the CHIMES model.

<u>TRUST-An Innovative User Interface for Scheduling</u>, Tom Sparn, University of Colorado

TDRSS Resource User Support Tool (TRUST) was developed to support TDRSS scheduling for flight projects at the Univ. of Colorado/Boulder including SME, SOLSTICE, TOPEX, and LDBP. It has also be used in planning and scheduling study efforts with GSFC including SURPASS, a comprehensive planning and scheduling tool for science experiment operations, which includes SN service schedule requests.

TRUST is implemented in Ada and embodies an expert system to aid scheduling generic TDRSS support and providing automatic rescheduling for conflict resolution. TRUST processes current operational and quality data messages with NCC, checks constraints, and performs trend analysis of the TDRS link. TRUST receives and processes spacecraft and TDRS visibility and orbital data. Request generation and processing is handled via a menu driven user interface. The graphical interface supplies a view of possible activities in science context.

The point was made that from the end user or science viewpoint, an integrated scheduling process for both SN and spacecraft resources is desirable. Color viewgraphs were included to demonstrate how TRUST operates.

<u>NCC User Planning System (UPS) User Interface</u>, Brian Dealy, Computer Sciences Corp.

UPS is a state-of-the-art replacement for the NCC Mission Planning Terminal which runs on Unix platforms with TAE+, a NASA developed graphical user interface based on X-Windows. UPS functions are to input and validate orbital data input and validate interactive and batch requests, transmit schedule acquisition requests (SARs) to the NCC, receive confirmed schedules, and report results.

UPS interactive features include a top level information window with pulldown menus, which provide access to all subsystem capabilities. The POCC positions which would use the UPS are the mission coordinator (who manages the data), the scheduler (who generates the requests), and the science user (who reviews the scheduling data). Tools assist the operator in mission setup (configurable for multiple mission support), database maintenance, and orbital data operations. UPS features automatic and specific schedule request generation (with default values where applicable), message transmission, and report generation.

The operator can choose between graphic and tabular formats, where tabular data is arranged in an easy to interpret format. A display shows interrelationships between SN services, events, interference and inter-mission conflicts for resources. Scrollable displays are used for the TDRS and mission spacecrafts and time periods scheduled. Viewgraphs were included to demonstrate UPS display techniques.

### 2.2.2 Session 2 Working Group Notes

Discussion topics for Session 2 considered human factors issues for both the SNC and user POCC operators, and addressed the information interface between the SNC and the POCC. This interface has both human and electronic elements.

The following four discussion topics were provided to the working groups.

> Session 2. SNC and User POCC Human-Computer Interface Concepts
>
> 1. Using presentation materials as a baseline, provide a definition of "generic scheduling" and make recommendations for its use in terms of concept, requirements, and implementation approach. Discuss incentives to make generic scheduling an attractive option for user POCCs and provide rationale.
>
> 2. Discuss the pros and cons of redefining the user POCC scheduling interface in conjunction with defining the SNC scheduling interface to the POCCs. Address the potential for providing common tools for user POCCs.
>
> 3. Scheduling system user interfaces guidelines are not mature today and standards are not expected in the foreseeable future. Suggest steps that should be taken to incorporate human factors guidelines for the human-computer interface into the system development process. Address risk areas.
>
> 4. Suggest an approach and discuss trade-offs for determining appropriate levels of automation for the SNC, for example, fully automated operations, human management by exception (supervisor role), human activated with computer assistance (computer recommends actions), or manual operations.

2.2.2.1 **Generic Scheduling**

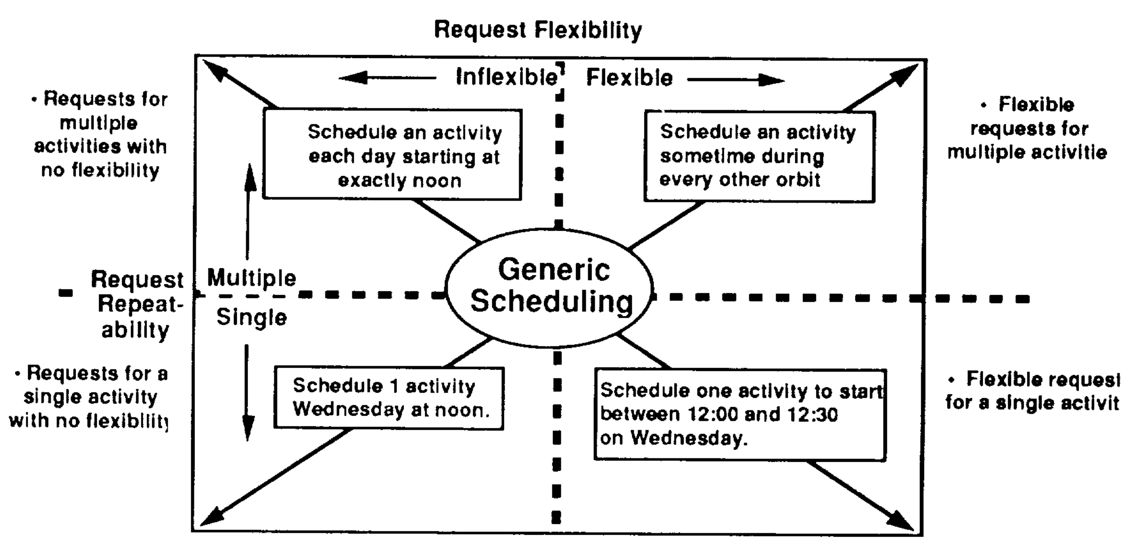
The working groups were asked to define generic scheduling and to make recommendations regarding its use, including incentives. They were given the following suggested definition and graphic shown in Figure 2-1.

Generic scheduling is a capability which allows scheduling of resources in response to user requests for single or repeated events in which time and resource requirements are expressed in a general way. Generic scheduling requests may include:

- Time expressed in terms of acceptable windows of absolute time or in terms of relative time (e.g., relative to orbital or other scheduled events).

- Resources expressed in terms of resource class and/or mandatory versus desired, (but optional) resources (e.g., willingness to accept one service without the other)

Figure 2-1 Generic Scheduling Definition




The first recommendation is to use the more appropriate name, "flexible request" scheduling, since the term generic request already has a special meaning. For example, the ATDRSS Phase B Operations Concept (S500-3) has a definition of generic scheduling which addresses only the repetition of a request. Also the NCC currently performs manual generic scheduling for tracking data. The concept discussed here is a considerably broader concept.

Flexible requests identify the resources and times that are required, how often a service is required, expiration dates of service need, and alternatives for a service if it isn't available. Flexible requests can be characterized as having:

- Two dimensions, flexibility and repeatability
- Three types of flexibility - time, request priority, and resource alternatives
- Specific requests as a special case, where flexibility is 0 with no repeats
- Definable dependencies/constraints
- Symbolic definitions which can be referenced by name
- Expressions of simple or complex relationships (a language).

A composite definition from all the groups follows.

#### 2.2.2.2 Definition for Flexible Requests

Flexible scheduling is a capability which allocates resources in response to user requests for single or repeated events (indicating service frequency) in which time and resource requirements are expressed in a general way. Flexible requests may include:

1) time expressed in terms of acceptable windows of (predetermined) absolute time, of relative time (e.g., relative to orbital events or other scheduled events), and of variable duration;

2) resources expressed in terms of resource class and/or mandatory vs desired (but optional) resources (e.g., willingness to accept one service without the other);

3) alternate service requests (if request A cannot be satisfied, substitute request B);

4) mechanisms for users to indicate request priority levels relative to their complete set of requests (i.e., within a system assigned range, users can select the priority level for a single request); and

5) expiration dates for repeatable events and expiration times for when tolerance is no longer viable (i.e., when a mission must have a commitment for allocated resources.

The ability for the scheduler to maneuver within the specified tolerance levels should be maintained as long as possible.

New Operations Concept

This flexible request approach represents a major change in operations concept. Today the user submits (and resubmits) specific requests with a yes/no response until satisfied or rejected. In flexible request scheduling, the user thinks through all options and codifies flexible service windows in a request language. The SNC scheduling system then has more information to work with in attempting to satisfy flexible requests, increasing the likelihood of success. The MO&DSD needs to help users develop a new network utilization concept during mission design in order to take advantage of the new capabilities flexible scheduling offers. It is suggested that SNC provide a help desk for assisting POCC users with the transition to flexible request scheduling.

As the scheduling problem is dependent on human judgement and cooperation, mutual trust between users and SNC is desirable. The SNC should believe that users won't overschedule because the likelihood of satisfying their requests is increased when the flexible options are specified. The users should believe that the SNC is giving them the best possible service because all the information to identify constraints and alternatives is provided in the request. Automated accounting of requests and of actual resource use by user is recommended to help establish trust and demonstrate that the SIRD commitments are being met. User POCCs may wish to approve the final instantiation of their flexible requests in the schedule.

SNC needs to demonstrate improved success rates (i.e., less time to produce a better result) with flexible requests in a realistic system model. Prototypes for proof of concept and/or shadow systems, schedule products to compare with the specific scheduling approach, and case studies are recommended. Possible studies to perform include analysis of the NCC scheduling negotiation process, time spent scheduling HST over a limited time period, and statistics on rejection rates during a Shuttle launch window.

Incentives are recommended to encourage users to submit flexible requests. Examples of incentives include a tax on disruptive requests, or conversely a discount for using a certain percentage of flexible requests, discounts for early submittal of service requests, or for maintaining flexibility late into the timeline. A multi-level "chip" method is suggested, where users are provided with a certain number of flexible request chips, and fewer specific request chips as an accounting mechanism.

Concerns

A number of concerns were raised. One involved the level of complexity introduced by a flexible request language approach. Concerns about the POCC passing too much information to the SNC also surfaced. The SNC is expected to handle orbital event times from missions as constraints. Some mission constraints can be very complicated, e.g., an instrument's view of spacecraft night and day may be dependent on the instrument's location on the spacecraft. Hence events could vary for different instruments on the same spacecraft. Specifying this type of constraint in a non-mission specific fashion is challenging. One approach is for the POCC to reduce these mission unique events into simpler time constraints.

Generic (repetitive) request scheduling is efficient for housekeeping, telemetry dumps, and other cyclical events, however it is not appropriate for one-time occurrences, which characterize many science events. Still, the flexible component of this approach is applicable to both kinds of events.

A concern exists that users may neglect to cancel repeated service requests they no longer need, when they maintain a standing generic request for services.

Training users and maintaining the language are also issues to study.

#### 2.2.2.3 Redefining the User POCC - SNC Interface

This discussion topic explored the benefits and issues in developing a new scheduling interface for the user POCCs in conjunction with defining a new SNC. Future SN users should have all capabilities available today. The new SNC is seen as an opportunity to redefine the user POCC interface and implement new capabilities, especially flexible requests. Flexibility options should be encouraged, but not forced. One concern is whether existing users would have to upgrade their interface or if the new interface would be downward compatible. Security issues imposed on the flexible scheduling approach, if any, should be studied.

Re-definition Approach

It is strongly recommended that the new interface be defined and engineered by a single team with representatives from both the SNC and the user POCCs. Then each group could develop their respective part, but with continued interaction throughout the system life cycle. Standardizing scheduling terminology across the SN is suggested to aid this process. The interface should include a standard scheduling language for describing flexible requests and common tools to enable POCCs to efficiently use the interface. Understanding the needs of different mission classes could help provide appropriate common tools. Increased use of electronic networks is recommended for information transfer, reducing the need for phone traffic. Also, POCCs should have standard access to scheduling data services (e.g., ephemerides, time representations) and mission elements (e.g., antenna models, spacecraft day/night calculations).

Tools

POCC users should be provided with a modular package or toolset to integrate in whole or in part into their system. Users may require specific tools for mission unique requirements, and they may want to combine SN scheduling with instrument planning. Therefore, tools should be provided with optional hardware and modular software which runs on multiple hardware platforms. A reusable, object-oriented library of tools is suggested. Finally, tool use should be promoted, but not mandated.

#### 2.2.2.4 Human-Computer Interface Guidelines

Working groups were requested to address risk areas and suggest steps that should be taken to incorporate human factors guidelines for the human-computer interface into the system development process.

Industry standards addressing general user interface guidelines do exist and should be applied to the scheduling domain, and especially to the prototypes. Prototypes should be completed as early as possible and before critical design reviews begin. In this way human-computer interface (HCI) issues specifically relevant to scheduling can be compiled, creating a library of lessons learned that crosses mission boundaries.

Operators and user class representatives who understand the scheduling process (not just the procedures in use today) should be involved in evaluating prototypes and throughout the SNC life cycle. User operators should be allowed to determine what is the best display, even allowing individual tailoring of displays within preset limits.

User interface technology exists today, which enables operations to develop and evolve their own standard displays. The capacity to easily change displays exists in tools such as TAE+, which provide data independence from display software. The operations concept should guide the definition of display contents, and human factors guidelines should be applied to develop common shells for this data. Providing a similar look and feel to displays eases training and use. Object oriented design approaches are recommended to better accommodate evolutionary changes.

Freezing user interface requirements too early and/or imposing a stringent scheduling language standard without adequate test and evaluation (via prototyping) are seen as key risk factors. Since scheduling operations represent a small and focussed group, the human factors engineering for SNC should emphasize expert users and tools for training, rather than attempting to accommodate novice users.

#### 2.2.2.5 SNC Levels of Automation

Determining the appropriate level of automation for SNC is another risk area which the groups were asked to discuss. The NCC project suffered from an approach that implemented a fairly manual system (automated schedule generation with manual conflict resolution). The development of automated tools to assist operators was anticipated, however funds were not forthcoming. Changes in the evolving SN took on higher priority, so automation aids never materialized.

Two viewpoints to consider are whether the SNC should basically be a manual system with automated pieces (e.g., tools), or an automated system which allows manual operations by exception. It is not a question of manual vs automated, but rather a question of where on the continuum between manual and fully automated will the SNC be designed. If the design starts too far to the manual side, achieving higher levels of automation may not be feasible later, as in the case of the NCC. Alternatively, automation without the appropriate system hooks would require substantial changes to give operators the insight they need.

One recommendation is to design the initial system to allow humans to make decisions (i.e., a decision support system). Operations personnel would identify routine decisions or procedures to delegate to machine processing (i.e., design algorithms to emulate human behavior). The converse recommendation stands on the premise that the SN scheduling problem is now well know and can be articulated and/or modeled by analysis of the existing system. Given this insight, a system could be designed with automated decision making capabilities, which provide operators with full visibility into the entire process, and allowing manual override by exception.

The SNC operations concept definition process should explore these ideas. The discussion notes tended to emphasize a human centered system with operator tools, rather than a machine centered system with human tenders. It is recommended to always keep man-in-the-loop, because of the need for human intuition and for intervention in certain decision making and conflict resolution problems. For example, decisions based on policy are subject to change and therefore risky to model in software. Mechanisms are needed to add tools as experience dictates.

Four methods recommended to determine automation requirements are task analysis, modeling, design team, and prototyping. Task analysis is used to identify and characterize tasks. The entire process, machine and manual procedures, must be analyzed with computer performance and operator skill being two criteria to consider. Automation should be based on which activities could be better performed by computer (e.g.,repetitive tasks). The CHIMES tool and MITRE RSA project demonstrate this process. An end-to-end paper model of the NCC is recommended, using survey information of NCC operators and users regarding scheduling system objectives (not necessarily procedures). The design team approach involves representatives from development, operations, user classes and management in developing design alternatives. One caution is to avoid biasing SNC towards current operations just because people tend toward what they already know. Objective guidance is needed to identify tasks which could be automated. Prototyping allows evaluation of a mix of automated and manual operations.

## 2.3 Resource Allocation Tools, Technology, and Algorithms

Several systems developed for specific projects were presented in this session to highlight the application of technology to similar scheduling problems.

### 2.3.1 Session 3 Presentation Highlights

AI Scheduling Techniques for HST , Mark Johnston, Space Telescope Science Institute

The Hubble Space Telescope (HST) offers one of the most challenging mission scheduling problems facing NASA. Scheduling HST involves 10 to 30 thousand observations per year, with approximately ten interacting constraints (operations, resource, science) for each observation. Constraint timescales range from seconds to many months. Observation pools are intentionally oversubscribed (~20%), with the goal to maximize HST science (i.e., highest priority science and maximum data quality). The spacecraft and ground system were designed assuming predictive scheduling would be adequate, however uncertainty of orbit accuracy and guide star availability is a major problem. This presentation focuses on the Artificial Intelligence (AI) methodology used for SPIKE, one of the key tools created to aid in the planning process.

The AI techniques implemented in SPIKE are used for constraint satisfaction techniques (search, constraint preprocessing) and weight-of-evidence combination for uncertainty reasoning. SPIKE supports automatic offline scheduling and graphical interaction by users to make scheduling decisions and diagnose problems. Its architecture features low-level constraint representation and propagation, and higher-level strategic scheduling (search).

The SPIKE approach incorporated development of a suitability function framework where the suitability function is based on the scheduling expert's assessment of the degree of preference for scheduling an activity at some time within constraints. The framework can also represent trade-offs among preferences, uncertainty in predicted scheduling conditions, implications of scheduling decisions as they are made, and implications of task execution as the schedule is implemented.

Intelligent Perturbation Algorithms for Space Scheduling Optimization, Cliff Kurtzman, Space Industries, Inc.

Optimizing a schedule generally results in a savings in time and money and by an increase in the fulfillment of mission goals. However, finding an exact, optimal solution to scheduling problems by searching is often not feasible, since the number of possible solutions is too large. Heuristic algorithms are then employed and can lead to a solution that is "good", but not always "optimal".

Intelligent perturbation heuristics are iterative refinement techniques and rely on "intelligent" search steps (rather than random) to systematically and quickly find good solutions. This technique has been implemented for Industrial Space Facility prototype experiment scheduler project. A more detailed paper is included in the Appendix C.

The search operator should be able to span the search space in a small number of steps. The computational overhead of iterations should be small, compared to the cost of producing a schedule. Search algorithms should have a random component for avoiding loops and breaking away from local optima.

A perturbation operator is used to increase rankings of activities not satisfied on previous iterations of the schedule, or rankings of bottleneck activities. Parameters can be adjusted to fit the structure of the particular scheduling problem, and the choice of parameters is key to finding good schedules (i.e., it is problem domain and policy dependent).

Iterative search techniques and parallel processing are enabling technologies for schedule optimization. Mouse/window style interactive user interfaces and object-oriented programming have aided the software development process for scheduling systems.

Combinatorial Optimization Techniques for Activity Scheduling, Surender Reddy, Computer Sciences Corp.

Producing a good initial schedule based on subjective analysis is labor intensive, impractical and unnecessary. Initial schedules can be based on computationally efficient polynomial time algorithms to optimize a general objective (such as maximizing the number of requests satisfied). The final schedule then evolves through changes and fine tuning, based on subjective analysis and human interaction.

A general approach combines optimization and heuristic techniques. Optimal single resource scheduling uses polynomial time optimization algorithms. Heuristic reasoning decomposes multiple resource problems into a series of single resource problems suitable for application of the single resource algorithms.

A proof of concept prototype was developed which can schedule specific and generic requests for TDRSS, DSN, and ground network services. It produced schedules with approximately 95% of the theoretically possible number of requests satisfied. The approach is applicable to initial batch scheduling and to certain cases of batch rescheduling.

Range Scheduling Aid, James Logan, MITRE

The Range Scheduling Aid (RSA) was developed to schedule the Air Force Satellite Control Network communication traffic. The initial approach involved scheduling on a paper wall chart completely by hand. MITRE's approach to developing a knowledge-based scheduling aid was to 1) replicate the current scheduling process in an automated environment; 2) develop a prototype based on user experience; and 3) create a user-friendly graphical interface.

The RSA features a graphical user interface with a similar look and feel to the paper wallchart, but with real-time response to human interactions. A constraint based analytical capability provides scheduling tools and automates human scheduler heuristics. RSA has a real-time multi-user system implemented on a portable workstation in Common Lisp.

The conflict resolution capabilities within RSA include identifying conflicts, oversubscribed resources and inadequate turnaround times. The tool provides explanations on conflict types and associated resources and times. Conflicts are resolved by listing possible solutions for single tasks and globally across time slices.

The technology transfer approach started with a known (manual) scheduling process, and incorporated known user interface features (codified scheduled events with color and patterns that mimicked the look and feel of the wall chart). The human schedulers' heuristics were then incorporated as computer aids in order to make their job easier and less prone to error.

Scheduling Techniques in ROSE, David Zoch, Loral AeroSys

The Request Oriented Scheduling Engine (ROSE) is a scheduling prototype that creates fast, automated conflict-free schedules. ROSE implements the Best First Search for Schedule Enhancement (BFSSE) post-processing algorithm among other rescheduling and contingency scheduling techniques. Graphical operator tools are provided for computer-assisted scheduling. ROSE goals are to:

- Reduce the time to generate a conflict-free schedule,
- Satisfy customers,
- Respond quickly to changes (targets of opportunity, Shuttle slips), and
- Implement NASA policy.

With ROSE users can submit flexible requests with preferences, constraints and alternatives by specified time. An initial conflict-free schedule is created by ROSE in 1-2 hours, with some requests not satisfied. Conflict resolution is performed by computer algorithms that imitate human conflict resolution processes (heuristics) in an attempt to schedule the remaining requests. The BFSSE conflict resolution approach identifies one unscheduled request and the algorithm repeats the following steps until either a solution is found or a timeout occurs: 1) select places on the schedule where the request almost fits; 2) move scheduled requests to place the unscheduled request; 3) reschedule all the moved requests by repeating the select/move steps for all moved requests.

A TDRSS scheduling prototype used ROSE to evaluate generic (flexible) scheduling requests for the predicted 1995 TDRSS workload. Different request selection, placement strategies, and scheduling algorithms were used. Flexible requests represented realistic contention for TDRSS resources with realistic view periods for eleven missions. Tradeoffs between success rates and time-to-schedule for the different scheduling algorithms were analyzed. This prototype verified the ability of a flexible request language (FERN) to realistically represent missions' needs with about 1700 requests/week (without Shuttle requests). Flexibility in user requests is key to the conflict resolution strategy and speed. (See Bibliography for reference on statistical results for the three scheduling architectures tested.)

<u>Managing Temporal Relations in MAESTRO</u>, Dan Britt, Martin Marietta

This presentation outlined the scheduling approach used by MAESTRO. This approach represents all available domain information to the scheduling system, including knowledge of activity structures, temporal constraints, resource types, use functions and availabilities, preferences in activity placement, resource use, schedule evaluation criteria and ways contingencies occur and are resolved computations are then performed to analyze and synthesize information. The domain and synthesized information is used to incrementally reduce the schedule search space for acceptable/good schedules. The majority of the search space is reduced implicitly by not allowing representable constraint violations.

MAESTRO, uses an opportunity algorithm for request placement. Temporal constraint propagation techniques specify acceptable time windows, and user specified criteria indicating importance of various heuristics are used for activity selection. An activity is defined as a sequence of subtasks, which accomplish goal(s). Each activity has associated resource, conditions, state, and timing requirements. Scheduling is defined as the start and end times for subtasks and their allocated resources.

Four types of temporal relations were described. The first was constraints on the placement of a single activity, (constraints include resources, conditions, time windows, activities of variable durations and delays, and relations of subtasks. The second temporal relation is the constraints between activities (e.g., precedes, follows, starts, one-way vs two-way constraints, relations to absolute times). The third relation is soft constraints representing general preferences (e.g., durations and delays), specific preferences (associate with a specific subtask, event or time), random placement and user placement. The last relation is contingency handling of late requests, bumping to fit new requests, and interrupting and restructuring an activity in real time.

Resource Representation in COMPASS, Barry Fox, MacDonnell Douglas

The COMPuter Aided Scheduling System (COMPASS) was developed for NASA to evaluate AI and advanced scheduling technology. It is written in Ada with an X-windows user interface. It is incremental, that is activities are added one at a time on a timeline, with knowledge of existing activities and resources. COMPASS is also interactive, with selection and placement of activities specified by user controlled commands. The order of adding activities and their location are independent.

In COMPASS, an activity is scheduled only if all required resources are available for the duration requested. The scheduling algorithm places activities on the timeline so that resource totals are not exceeded. Interactive and automated subsystems support both internal and external (textual) representations of resource requirements and availability.

COMPASS represents resource requirements by piecewise linear functions, where the origin is relative to the beginning of the activity. An activity may be a consumer or producer of resources. Positive quantities represent amounts required and negative quantities represent the amount provided by an activity. Activities are represented as ordered list of segment descriptors and linked lists using the Ada generic list package. Object-oriented dotted notation is used (e.g., crew.ss.bob and crew.ss.alice can be selected by specifying crew.ss or just crew) and special notations for time are also featured.

The placement algorithm locates a time where the activity's resources can be satisfied and subtracts those resources from the availability function. Unscheduling is performed by adding resources back. Since resource availability is also represented by piecewise linear functions, placing activities on the timeline is performed in segments.

One of COMPASS's key features is that it was developed as an open system. Hence full source code and complete documentation are available, enhancing its reusability.

### 2.3.2 Session 3 Working Group Notes

The groups were asked to identify key performance parameters from the viewpoints of the user POCC, SNC operations, schedule efficiency, and system development. User POCC and SNC operations comments relate to the process implemented for generating schedules, whereas schedule efficiency relates to the schedule as a product. Comments on applications of artificial intelligence and other techniques, as well as risk areas, were also solicited.

The following discussion topics and instructions were provided.

Session 3. Resource Allocation Tools, Technology, and Algorithms

1. Identify at least 3 key performance parameters for the following viewpoints:

a) User POCC
b) SNC operability
c) SN schedule efficiency
d) System implementation

Include a sentence or two, as needed, to explain/clarify each parameter.

2. Select at least 3 of the performance drivers above and suggest ways of satisfying them. Address application of AI and other techniques and identify risk areas.

3. Identify candidate SN resource allocation prototyping objectives. Provide rationale.

Performance drivers for the SNC are summarized in the next four sections, followed by a section on recommendations for prototyping.

#### 2.3.2.1 User POCC Accountability

The following metrics are recommended for accountability to users:

- Number and percent of requests scheduled according to user-defined priorities and mission goals
- Requests altered with rationale
- Requests rejected with rationale
- Response time for initial scheduling from requests
- Response time for scheduling change requests
- Response time for near real-time changes

- Lead time required by SNC for submitting requests
- Lead time needed to develop requests

Common tools for easy user access to scheduling information and communications with SNC are recommended. Suggestions for scheduling information to be provided to the users include:

- Intermediate feedback on ongoing processes
- Routine feedback on how well SNC is working (automated statistics)
- Long term loading analysis (identify busy weeks)
- Notification of opened slots, available resources

Other SNC supplied user assistance is recommended as follows:

- Staff a help desk
- Educate users on scheduling options and ways to optimize requests
- Provide adequate visibility into the scheduling process
- Identify level of risk associated with particular events
- Provide tools for learning and using a flexible request language

Several user POCC concerns which affect scheduling performance were discussed. For example, the compatibility of the SN scheduling process with the user's mission goals and the reliability of the schedule commitment from the SNC (i.e., the stability of the published schedule) were raised as issues. There was also a concern that automated tools may allow their users to acquire more resources than users with manual methods.

#### 2.3.2.2 SNC Operability

The following metrics (in addition to those mentioned above for user POCCs) are recommended for SNC operations accountability:

- Time to generate schedule/update schedule
- Ratio of the time to generate (runtime and wall clock-time) to the length of the schedule (e.g., should require hours or less to generate a week long schedule)
- Interactive system response time (e.g., HCI updates, graphics, etc.)
- System response time during high interaction (e.g., conflict resolution)
- Number of iterations between subsystems
- Number/type of interactions with users
- Downtime for maintenance (tools provided)
- Percent of operator's time required for normal operations
- Quality of operator attention/skill needed

Suggested parameters for assessing ease of use and operations costs are:

- Number of operators required
- Time to train, tools for training

- Skill level required
- Number/type of errors made
- Level of assistance system provides
- Forgiving system response to operator input errors (undo)
- Automatic high level checks on operator inputs
- Use of standard interfaces and procedures

Robust operations are dependent on the ability to do the following:

- Accommodate change in SN (e.g., new ground terminals, new users)
- React to critical events (regenerate/disseminate schedule)
- Meet users need in event of launch slip
- Create and maintain multiple schedules

Possible uses of SNC accounting statistics are to monitor operations, manage trends and adjust priorities, assess success in meeting mission SIRD (i.e., compare actual support to negotiated support), and to provide feedback to users.

### 2.3.2.3 SN Schedule Efficiency

The following metrics for assessing scheduling efficiency are suggested:

- Resource utilization (level usage distribution)
- Percent of un-allocated resources, noting utility (e.g., fragmented or not)
- Number of events scheduled per time increment
- Number of conflicts and ease of resolution
- Number of events affected by contingency, duration of time affected by ripple (resiliency)
- Resource allocation data to monitor trends, determine if the SN is oversubscribed

How to measure user satisfaction with the resultant schedule is a difficult question, but some insight into the quality of the schedule can be assessed by the following:

- Percent of requests satisfied (total and by mission, during forecast and active period in, preferred and degraded service modes)
- Difference between user's requests and actual resource utilization

Several areas of concern include understanding and minimizing the impact of the rescheduling process on the schedule handling peak service loads, and responding to contingencies. There was a suggestion to define metrics for responses and to model contingencies. A cost/benefits trade analysis of optimization techniques is needed. Regarding optimization, no system totally optimizes a schedule, rather systems evaluate alternatives and pick the best schedule from among those alternatives.

### 2.3.2.4 System Implementation

The recommended system development and performance factors to monitor include:

- Time and cost (source lines of code productivity measure);
- Maintainability;
- Tradeoff between flexibility and complexity;
- Time to implement a new function;
- Time to upgrade or port to a new platform;
- Test time needed (benchmark set of requests should be provided for testing);
- Percent commercial off-the-shelf components;
- Computer processing time to generate schedule (CPU utilization);
- Message latency;
- HCI response time.

Adequate development resources, in terms of time, funds, equipment and tools (development environment) are needed to increase productivity and maintain an audit trail. These requirements are especially important for building an extensible and adaptable system. The use of standards (especially interface standards) and common, modular (table driven) components is recommended to allow components to be added, upgraded, and automated by modifying algorithms, resetting parameters, and replacing modules.

### 2.3.2.5 Prototyping

Suggested prototyping goals are to validate operations concepts, involve users (schedule operators and POCC users), inject innovation, guide the level of automation, mitigate risks, and capture lessons learned (i.e., the problems and successes of NCC and prototypes).

Suggested prototype approaches include introducing the SNC scheduler prototype in a "shadow mode". By using the prototype as a scheduling advisor system, the operator would gain confidence in the new technology. Off-the-shelf components should be considered for prototype development. Finally, successful prototypes developed before the SNC contract award could be provided as government furnished equipment.

Potential activities for prototyping are categorized into six areas: studies, operations concept, user POCC needs, flexible request language; scheduler interface; and scheduling techniques.

Studies

- Survey technology developments, determine unique features of each and their applicability to SNC.

- Measure performance characteristics, such as manhours to generate a schedule in the NCC, as a baseline to compare with prototypes.

- Define the "goodness" of a schedule. Suggested parameters are the percent of SN resources used, the total number user requests satisfied, the percent of each user's requests satisfied, and the amount of science return, among others.

Operations Concepts

- Base the prototype implementation on an operations concept, not vice versa, and validate the concepts.

- Generate multiple operations scenarios including nominal operations, spacecraft emergency, ATDRSS outage, and Shuttle launch slips.

- Show the feasibility of generating alternate schedules (e.g., for Shuttle slips).

- Compare timeline processes of scheduling/editing/rescheduling vs interactive scheduling.

User POCC Needs

- Identify user information needs; consider schedule visibility and security needs.

- Identify mission critical and fast reaction functions.

- Evaluate different priority schemes and their effects on meeting user goals and SNC commitments (stated in SIRD).

- Investigate how scheduling goals may differ in forecast vs active periods.

Flexible Request Language

- Determine information flow between the SNC and user POCC interface for schedule generation through execution. Address the balance between flexibility and complexity.

- Verify the flexible request language approach (benefits vs complexity). Note experience in MO&DSD Scheduling Concepts, Architectures and Networks (SCAN) testbed which implemented the FERN flexible request language, for instrument scheduling.

Scheduler Interface

• Evaluate information coding with color, patterns and text (consider MO&DSD ground network scheduling system, CAIRS, for method of naming events).

• Consider a "graphical phone call" technique, which allows the POCC and SNC to view the same information in resolving conflicts.

Scheduling Techniques

• Prove feasibility of scheduler extensibility approach (end-to-end prototyping of modular elements).

• Identify the best algorithms. Note MO&DSD algorithm evaluation tasks in support of the NCC.

• Investigate AI approaches such as Stanford Telecom's LA-2D algorithm, A* algorithm, and/or the use of schedule quality metrics as search drivers.

# Section 3—Conclusions

The SNC Conference on Resource Allocation Concepts and Approaches proved to be a fruitful forum for suggesting ideas and discussing issues for the SNC. The three items summarized below capture the main themes of the conference.

## 3.1 Key Recommendations

- Management criteria for success - The quality of a schedule tends to be in the eye of the beholder. To alleviate perception problems with SNC produced schedules, it is recommended that specific measures of schedule quality be routinely evaluated and provided to the users. An online automated accounting capability is recommended to maintain statistics on resource utilization, request disposition and turnaround time, and schedule generation and update time.

- Level of automation - A more automated decision support system is recommended for SNC. Automated tools are needed to aid human operations, incorporating improved human-computer interface techniques which support the interpretation of data and the direct manipulation of interface functions.

- New SNC - User POCC interface - A flexible scheduling request language for specifying SN service requests is recommended. Both specific requests (e.g., data in a Schedule Add Request) and flexible requests (e.g., a single request for a routine repetitive return service for at least 10 minutes every orbit) need to be supported. The concept implies that access to scheduling information, such as orbital data for user antenna view periods, will be available to the SNC. An SNC help desk and modular tools should be provided to the user POCC to ease the implementation of a new interface.

## 3.2 Concerns

Concerns such as developing the SNC to accommodate changes in the SN, system engineering in a distributed environment, and security issues were raised. In addition, risks related to the key recommendations were addressed and are summarized below.

- Level of automation - A key question for the system definition phase is whether the SNC is automated with full operator visibility for manual override, or if it supports human decision making with automated tools.

- Scheduler performance - Another key risk area is scheduler performance, measured by 1) the time to generate a schedule, 2) meeting scheduling goals set by management, and 3) schedule resiliency (i.e., the ability to minimize disturbance to the overall schedule due to rescheduling activities).

- Flexible requests - A trade off between the degree of flexibility sufficient for SN scheduling and the complexity of the SNC and user POCC interface must be assessed. Assuring efficient use of resources (e.g., avoiding overscheduling) and minimizing the impact of a new user interface on existing missions are also concerns.

- Access to scheduling data - Scheduling information needed to interpret constraints comes from many sources, including the SN elements, Flight Dynamics, and the POCCs. Determining who has responsibility for providing scheduling data access and maintenance is a systems engineering issue.

## 3.3 Prototyping

Throughout the conference, prototyping was continually mentioned as an effective mechanism for verifying operations concepts and evaluating specific technology risks. Rapid prototypes can be used to illustrate operations concepts, and more detailed prototypes may implement a subset of SNC functions for a proof of concept or for performance evaluation (e.g., a scheduling engine prototype). Modelling and human factors task analyses are also recommended.

Goals for SNC prototyping are to involve users, both from the POCCs and from SNC operations, in evaluating automation approaches, in assessing innovation and risk areas, and in capturing lessons learned for the SNC. Operations scenarios are needed to define both nominal schedule generation as well as non-nominal situations (e.g., rescheduling for emergencies, equipment outages, Shuttle launch slips).

Two key activities recommended for evaluation address the scheduling timeline. Alternatives for schedule generation need to be investigated to compare batch processing (e.g., forecast/active periods) versus continual incrementally updated schedule processing. The concepts of parallel alternative schedule generation and wait lists for contingency planning need to be investigated by prototyping.

Many of the recommendations are being pursued or investigated in the various SNC development tasks. A prototyping effort for SNC is underway to address as many of the suggested topics as time and funding will support. An initial testbed is planned to be established by the end of FY91 and will include an SNC scheduling prototype and a user POCC workstation interface. The testbed operations scenario will demonstrate the use of a flexible scheduling request language and operator tools for generating and maintaining an SN schedule. Those involved in the SNC development will continue to seek input and guidance from individuals and institutions involved in SN scheduling.

# Appendix A—Conference Briefing Handouts

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AND DATA SYSTEMS DIRECTORATE

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# SPACE NETWORK CONTROL (SNC) CONFERENCE ON RESOURCE ALLOCATION CONCEPTS AND APPROACHES

December 12 & 13, 1990

NASA
National Aeronautics and
Space Administration

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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## SPACE NETWORK CONTROL CONFERENCE ON RESOURCE ALLOCATION CONCEPTS AND APPROACHES

### DECEMBER 12 - 13, 1990

### WORKING GROUP DISCUSSION QUESTIONS

### SUGGESTION:

Keep a running list of concepts/issues that may be considered for SNC as you listen to the briefing.

Examples:

- Distributed systems and information access
- Locus of control
- Level of automation
- Timeline management
- Generic scheduling
- Impact of demand access
- Impact of "classes" of users on scheduling services

### SESSION 1. CONCEPTS FOR SPACE NETWORK RESOURCE ALLOCATION

1. Identify the three most critical issues for Space Network Resource Allocation in terms of:

   a. Management
   b. Operations
   c. SN User POCCs
   d. System Development

   Include a sentence or two, as needed, to explain/clarify each issue.

2. Select at least three of the critical issue above and suggest ways of resolving them. Address innovation and risk factors. Identify areas for further study and suggest study approaches.

3. Discuss how resource allocation might be performed for:

   a. Rescheduling in the event of a failure to the ATDRSS Ground Terminal.

   b. Scheduling of previously allocated resources that unexpectedly become available (e.g., shuttle launch slips).

4. Discuss the pros and cons of dividing the schedule timeline into forecast (batch) and active (incremental updates) periods. Suggest alternative schedule timeline approaches for SNC consideration.

5. Given that there are different user classes, discuss the pros and cons of subdividing available resources into multiple subnetworks based on user classes and demands for use by each user class.

## SESSION 2. SNC AND USER POCC HUMAN-COMPUTER INTERFACE CONCEPTS.

1. Using presentation materials as a baseline, provide a definition of "generic scheduling" and make recommendations for its use in terms of concept, requirements, and implementation approach. Discuss incentives to make generic scheduling an attractive option for user POCCs and provide rationale.

2. Discuss the pros and cons of redefining the user POCC scheduling interface in conjunction with defining the SNC scheduling interface to the POCCs. Address the potential for providing common tools for user POCCs.

3. Scheduling system user interfaces guidelines are not mature today and standards are not expected in the foreseeable future. Suggest steps that should be taken to incorporate human factors guidelines for the human computer interface into the system development process. Address risk areas.

4. Suggest an approach and discuss trade-offs for determining appropriate levels of automation for the SNC, for example, fully automated operations, human management by exception (supervisor role), human activated with computer assistance (computer recommends actions), or manual operations.

## SESSION 3. RESOURCE ALLOCATION TOOLS, TECHNOLOGY, AND ALGORITHMS

1. Identify at least three key performance parameters for the following viewpoints:

   a. User POCC
   b. SNC operability
   c. SN schedule efficiency
   d. System implementation

Include a sentence or two, as needed, to explain/clarify each parameter.

2. Select at least three of the performance drivers above and suggest ways of satisfying them. Address application of AI and other techniques and risk areas.

3. Identify candidate SN resource allocation prototyping objectives. Provide rationale.

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# SPACE NETWORK CONTROL (SNC) CONFERENCE ON RESOURCE ALLOCATION CONCEPTS AND APPROACHES

## INTRODUCTION

**DECEMBER 12, 1990**

**W. WATSON/530**
**ASSISTANT CHIEF FOR**
**NETWORK PLANNING**

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| MO&DS DIRECTORATE | SPACE NETWORK CONTROL (SNC) CONFERENCE ON RESOURCE ALLOCATION CONCEPTS AND APPROACHES <u>INTRODUCTION</u> | GSFC |
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<u>GOALS FOR CONFERENCE ON RESOURCE ALLOCATION</u>

- SURVEY EXISTING RESOURCE ALLOCATION CONCEPTS AND APPROACHES.
- IDENTIFY SOLUTIONS APPLICABLE TO THE SN PROBLEM.
- IDENTIFY FRUITFUL AVENUES OF INVESTIGATION IN SUPPORT OF SNC DEVELOPMENT.
- CAPTURE KNOWLEDGE IN PROCEEDINGS AND MAKE AVAILBLE TO BIDDERS ON THE SNC CONCEPT DEFINITION PROCUREMENT.

A-2

| MO&DS DIRECTORATE | SPACE NETWORK CONTROL (SNC) CONFERENCE ON RESOURCE ALLOCATION CONCEPTS AND APPROACHES |
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| CODE 500 | INTRODUCTION |

## BACKGROUND

- THE CURRENT NCC WORKS, PROVIDING A VARIETY OF SCHEDULING AND TECHNICAL MANAGEMENT FUNCTIONS FOR THE SPACE NETWORK (TDRSS), THE GROUND NETWORK (MIL,BDA, DKR) AND INTERFACE TO OTHER NETWORKS (DSN, RTS)
- THE SPACE NETWORK IS CHANGING:
  - TDRS CLUSTER ARCHITECTURES
  - WHITE SANDS GROUND TERMINAL COMPLEX
  - NEW ATDRSS SERVICES
  - MIXED FLEET TDRS/ATDRS
  - INTERNATIONAL DATA RELAY SATELLITE INTEROPERABILITY
- AS THESE CHANGES PROGRESS, THE CURRENT NCC SYSTEM AND SOFTWARE ARCHITECTURE BECOMES INCREASINGLY DIFFICULT TO MAINTAIN.

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| MO&DS DIRECTORATE | SPACE NETWORK CONTROL (SNC) CONFERENCE ON RESOURCE ALLOCATION CONCEPTS AND APPROACHES |
|---|---|
| CODE 500 | INTRODUCTION |

## GOALS FOR SPACE NETWORK CONTROL

1. DEVELOP A SYSTEM ARCHITECTURE CAPABLE OF ACCOMMODATING CHANGE
   - HARDWARE
   - SOFTWARE
   - INTERFACES
   - SPAN OF CONTROL
2. IMPROVE SN USER SATISFACTION
   - SN USER INTERFACE - VARYING LEVELS OF USER SOPHISTICATION & NEED
   - % OF SUPPORT REQUESTS GRANTED - A SCHEDULING ISSUE
3. IMPROVE THE SN INSTITUTIONAL UTILIZATION AND EFFECTIVENESS
   - SNC LIFE CYCLE COSTS: OPERATIONS AND SYSTEM MAINTENANCE
   - INCREASE THE UTILIZATION OF THE SN
     - 5% INCREASE MAY SAVE THE COST OF AN ATDRS OVER THE 15 YEAR PROGRAM LIFE CYCLE ($200M - $300M)
     - THIS IS BOTH A SCHEDULING AND SYSTEM RELIABILITY ISSUE

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| MO&DS DIRECTORATE | SPACE NETWORK CONTROL (SNC) CONFERENCE ON RESOURCE ALLOCATION CONCEPTS AND APPROACHES |
|---|---|
| CODE 500 | INTRODUCTION |

### BACKGROUND

- THE CURRENT NCC WORKS, PROVIDING A VARIETY OF SCHEDULING AND TECHNICAL MANAGEMENT FUNCTIONS FOR THE SPACE NETWORK (TDRSS), THE GROUND NETWORK (MIL,BDA, DKR) AND INTERFACE TO OTHER NETWORKS (DSN, RTS)
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| MO&DS DIRECTORATE | SPACE NETWORK CONTROL (SNC) CONFERENCE ON RESOURCE ALLOCATION CONCEPTS AND APPROACHES |
|---|---|
| CODE 500 | INTRODUCTION |


### GOALS FOR SPACE NETWORK CONTROL

1. DEVELOP A SYSTEM ARCHITECTURE CAPABLE OF ACCOMMODATING CHANGE
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        - THIS IS BOTH A SCHEDULING AND SYSTEM RELIABILITY ISSUE

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# SNC Conference on Resource Allocation Concepts and Approaches

## Conference Format

December 12, 1990

K. Moe/522

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| MO&DS DIRECTORATE | SNC Conference Format |
| CODE 500 | |

## Conference Format

- Conference Introduction
- Session 1: Concepts for SN Resource Allocation
- Session 2: SNC and User POCC Human-Computer Interface Concepts
- Session 3: Resource Allocation Tools, Technology, and Algorithms
- Working group discussions will follow each session
- Each presentation will be approximately 20 minutes
- Conference proceedings will be published early in 1991 and will contain:
  - Presentation Slides/Presentation Papers
  - Working Group Results

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## Working Group Discussions

- Working groups will consist of:
  - Leader
  - Recorder
  - Approximately 8 members total
- Working groups will address specific "questions to be answered" in the conference handout
- Leader and Recorder will be responsible for the documentation of working group efforts
- Everyone is encouraged to take notes during presentations to capture ideas
- Your participation and contributions to working group discussions are essential elements of this conference

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| MO&DS DIRECTORATE | SNC Conference Format | GSFC |
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## Working Group Discussions (Cont'd)

- Working Group Leaders
  - Dorthy Perkins
  - Pepper Hartley
  - Philip Liebrecht
  - Candace Carlisle
  - Vern Hall
  - Doug McNulty
  - BJ Hayden
- Working Group Recorders
  - Eric Richmond
  - Beth Antonopulos/Brian Dealy
  - Lisa Karr
  - Bill Potter
  - Nancy Goodman
  - Ken Johnson
  - Karen Thorn

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**Agenda**

December 12, 1990

| | | |
|---|---|---|
| 8:00 | - 8:30 | Registration |
| 8:30 | - 9:30 | Conference Introduction |
| 9:30 | - 11:15 | Session 1: Concepts for SN Resource Allocation |
| 11:15 | - 12:15 | Lunch |
| 12:15 | - 1:00 | Session 1 (Cont'd) |
| 1:00 | - 3:30 | Session 1 Working Group Discussions |
| 3:30 | - 5:00 | Session 2: SNC and User POCC Human-Computer Interface Concepts |

December 13, 1990

| | | |
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| 8:00 | - 9:15 | Session 2 (Cont'd) |
| 9:15 | - 11:15 | Session 2 Working Group Discussions |
| 11:15 | - 12:15 | Lunch |
| 12:15 | - 3:15 | Session 3: Resource Allocation Tools, Technology, and Algorithms |
| 3:15 | - 5:00 | Session 3 Working Group Discussions |
| 5:00 | | Concluding Remarks |

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NASA

# SCHEDULING OVERVIEW AND CHALLENGES

NOVEMBER 1990

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SCHEDULING OVERVIEW AND CHALLENGES

## INTRODUCTION

- THE NCC IS RESPONSIBLE FOR THE ALLOCATION OF SPACE NETWORK RESOURCES TO MEET AUTHORIZED USER REQUIREMENTS.
  - SCHEDULES TDRS AND WSGT
  - SCHEDULES NASCOM
  - SCHEDULES NASA GROUND TERMINAL
  - SCHEDULES SDPF

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| MO&DS DIRECTORATE | SCHEDULING OVERVIEW AND CHALLENGES |
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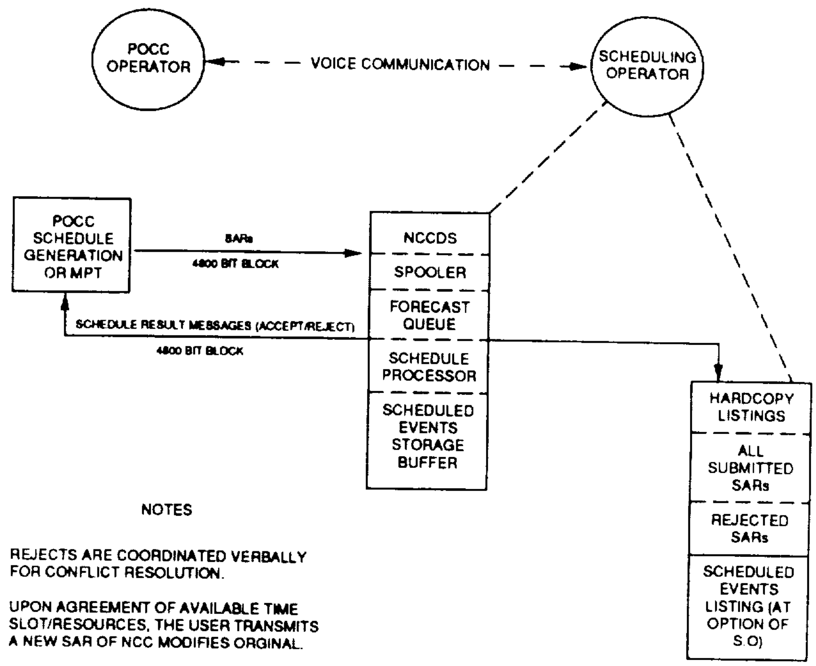
# SCHEDULING PROCESS




NOTES

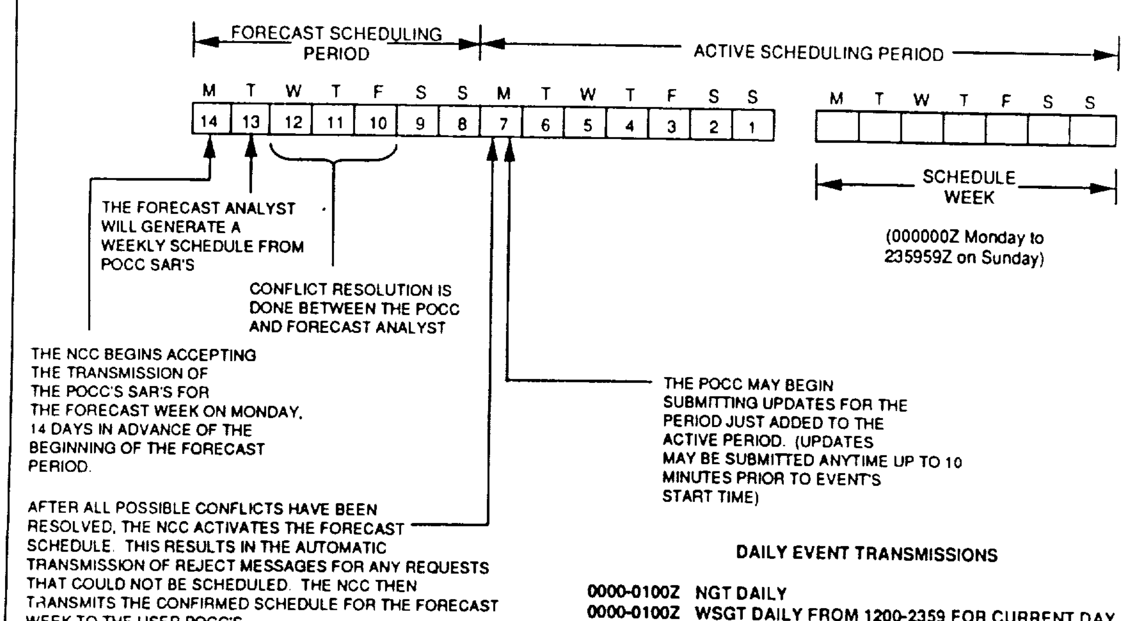
REJECTS ARE COORDINATED VERBALLY FOR CONFLICT RESOLUTION.

UPON AGREEMENT OF AVAILABLE TIME SLOT/RESOURCES, THE USER TRANSMITS A NEW SAR OF NCC MODIFIES ORGINAL.

C-3

| MO&DS DIRECTORATE | SCHEDULING OVERVIEW AND CHALLENGES |
|---|---|
| CODE 500 | |

# SCHEDULING TIMELINE



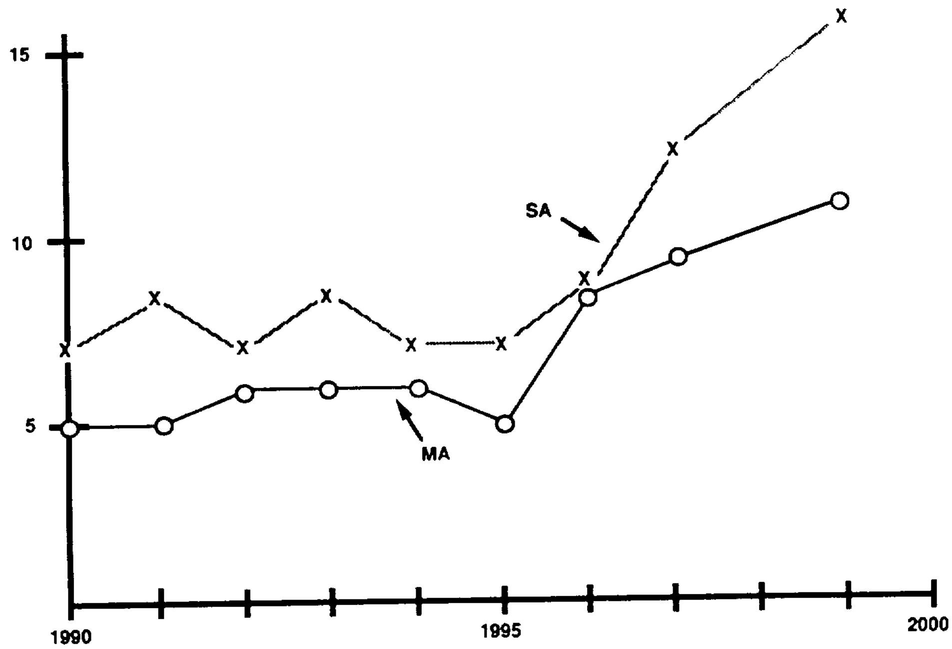

DAILY EVENT TRANSMISSIONS

| | |
|---|---|
| 0000-0100Z | NGT DAILY |
| 0000-0100Z | WSGT DAILY FROM 1200-2359 FOR CURRENT DAY |
| 1200Z | WSGT DAILY FROM 0000-1159 FOR UPCOMING DAY |
| 2200Z | NASCOM/SDPF DAILY FOR UPCOMING DAY |

C-4

| | |
|---|---|
| MO&DS DIRECTORATE | SCHEDULING OVERVIEW AND CHALLENGES |
| CODE 500 | |

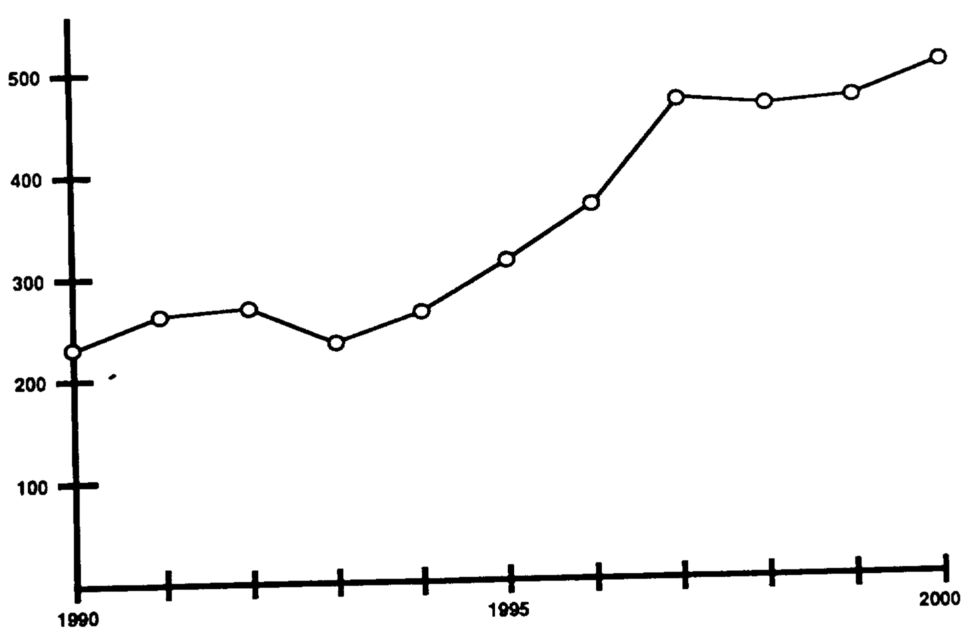
## NUMBER OF SN USERS




C-5

| | |
|---|---|
| MO&DS DIRECTORATE | SCHEDULING OVERVIEW AND CHALLENGES |
| CODE 500 | |

## SN EVENTS PER DAY
### PEAK DAILY LOADING




C-6

# SCHEDULING CHALLENGES

- CURRENT
  - EFFICIENT USE OF NETWORK RESOURCES
  - SCHEDULING SHUTTLE - MINIMIZE IMPACT ON OTHER USERS
  - USER POCC INTERFACE
  - REFINE FORECAST/ACTIVE PERIOD PROCEDURES
  - SCHEDULING AROUND RFI
  - BETTER TOOLS FOR CONFLICT RESOLUTION - EMPHASIS ON AIDING SCHEDULER, NOT REPLACE/AUTOMATE

C-7



# SCHEDULING CHALLENGES (CONTINUED)

- FUTURE
  - SCHEDULING CONTROL - MAN AND MACHINE FUNCTIONS
  - GENERIC SCHEDULING - TAKE INITIATIVE, DON'T REACT
  - TRANSITION
    - TDRSS TO ATDRSS
    - NCC TO SNC
  - SSF SCHEDULING
  - INTERNATIONAL SPACE NETWORK INTEROPERABILITY
  - SPACECRAFT PROXIMITY OPERATIONS (E.G., SHUTTLE DELIVERY, SSF)
  - DEMAND ACCESS

C-8

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N92-11041

Presented to

Symposium on Planning and Scheduling

Prepared for

Goddard Space Flight Center
Mission Operations & Data Systems Directorate
Code 520

Prepared by

NASA Programs Office
CTA INCORPORATED
6116 Executive Boulevard
Rockville, Maryland 20852

December 12, 1990

D-1

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## What We Were Asked to Do

- Document planning and scheduling lessons learned
- Provide recommendations
- Relate lessons learned to mission characteristics

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## What We Did

- Conducted, documented, and validated 32 interviews
  - Missions included were: COBE, ERBS, EP/EUVE, HST, LANDSAT, SME, SMM, STS
  - Institutional facilities included were: CMF, FDF, MSOCC, NASCOM, NCC
  - Persons interviewed included: Scientists, operations personnel, managers, software engineers
- Identified lessons learned from raw data collected in interviews
- Analyzed lessons learned across missions and facilities
- Identified relevant mission characteristics and analyzed their relationships to the lessons learned
- Developed/formulated recommendations that address the lessons learned perceived as having a major impact on the planning and scheduling process



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## Major Recommendations

- Operational concepts are introduced much too late in the mission cycle.

**1. Develop end-to-end planning and scheduling operations concepts by mission class and ensure their consideration in system life cycle documentation.**

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## Background - Recommendation 1

- Persons interviewed consistently expressed the need for considering operational implications early in mission life cycle
- Systems Instrumentation Requirements Document (SIRD) frequently developed before the Mission Operations Concept Document
- Detailed analysis of operational factors might have avoided subsequent planning and scheduling problems (e.g., inability of NCC to support cross-support required by HST)



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## Details - Recommendation 1

- Develop mission operations concepts to include non nominal sequences
- Develop guidelines/document outlines and timelines for system documentation
- Require traceability between system documentation and the mission operations concept

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## Major Recommendations

- The lack of an adequate end-to-end planning-and scheduling systems engineering approach has resulted in fragmentation in mission planning and scheduling.

2. **Create an organizational infrastructure at the Code 500 level, supported by a Directorate-level steering committee with project representation, responsible for systems engineering of end-to-end planning and scheduling systems.**



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## Background - Recommendation 2

- Planning and scheduling systems are developed in disjoint pieces
- Excessive verbal communication and iteration are required to compensate for system engineering deficiencies
- Fragmentation transcends MO&DSD to divisions, flight projects, and users

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## Details - Recommendation 2

- Include technical committee representing all divisions, Advanced Missions Analysis Office, and each project in the flight Projects Directorate
- Analyze and coordinate technical decisions that transcend individual divisions within MO&DSD
- Ensure that systems are specified and developed within the framework of an end-to-end information flow analysis
- Support interactions with other organizations (e.g., Flight Projects Directorate) concerning planning and scheduling implications of high level decisions (e.g., spacecraft design and operations concept)
- Oversee development of a strategy for integration of all MO&DSD planning and scheduling elements
- Ensure operational user evaluation



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## Major Recommendations

- Problems in mission planning and scheduling systems are exacerbated, but not created by, identifiable mission characteristics that are established in the Phase A timeframe of a mission's life cycle.

**3. Develop and refine mission modeling capabilities to assess impacts of early mission design decisions on planning and scheduling.**

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## Background - Recommendation 3

- Mission characteristics related to spacecraft design and the mission operations concept can exacerbate planning and scheduling problems
- Discrepancies can exist between flight project and MO&DSD regarding expected availabilities and capabilities of institutional resources (e.g., TDRSS)
- Difficulty in capturing and analyzing dynamic relationships using traditional methods for specifying operations concepts (e.g., text & block diagrams)

NAS 5 30680
D-11

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## Details - Recommendation 3

- Assess impacts of early mission design decisions on planning and scheduling, particularly space-to-ground communications requirements
- Facilitate analysis of dynamic aspects of mission concept
- Support consistency and traceability between the Mission Operations Concept Document and subsequent specifications

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## Major Recommendation 4

- The current approach to scheduling, both within the NCC and in most missions, does not provide sufficient flexibility and is a major factor in the rescheduling problem.

4. **Emphasize operational flexibility in the development of the Advanced Space Network, other institutional resources, external (e.g., project) capabilities and resources, operational software and support tools.**

NAS 5 30680 13

D-13

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## Background - Recommendation 4

- Most planning and scheduling systems are designed to support a single operations concept
- Difficulties arise when unanticipated events force a deviation from the nominal sequence
- Variation in needs of missions are not accommodated in current systems (e.g., fixed NCC timeline)

- Include service-level request disposition, extensible contacts, flexible timelines
- Institutional resources (e.g., NASCOM, FDF) should accommodate nominal and non-nominal sequences of planning and scheduling activities

N92-11042

# CONCEPTS, REQUIREMENTS, AND DESIGN APPROACHES FOR BUILDING SUCCESSFUL PLANNING AND SCHEDULING SYSTEMS


PART I: A PROGRAMMATIC PERSPECTIVE
*RHODA SHALLER HORNSTEIN*
*NASA / OFFICE OF SPACE OPERATIONS*

PART II: A TECHNICAL PERSPECTIVE
*JOHN K. WILLOUGHBY*
*INFORMATION SCIENCES, INC.*



SPACE NETWORK CONTROL CONFERENCE
NASA / GSFC

DECEMBER 12, 1990


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F-1

## PRESENTATION OUTLINE

*PART I: A PROGRAMMATIC PERSPECTIVE*

- STATING THE MANAGEMENT CHALLENGE
- DISSECTING THE MANAGEMENT CHALLENGE
- RESPONDING TO THE MANAGEMENT CHALLENGE
- FOCUSING THE TECHNICAL PERSPECTIVE
- SUMMARY

*PART II: A TECHNICAL PERSPECTIVE*

- REQUIREMENTS THAT ARE UNLIKE OTHER SYSTEMS
- GOOD AND BAD STARTING POINTS FOR THE DESIGN
- PROJECTING THE CONSEQUENCES OF OPERATIONS CONCEPTS
- SUMMARY

## STATING THE MANAGEMENT CHALLENGE

HOW CAN THE TRADITIONAL PRACTICE OF

SYSTEMS ENGINEERING MANAGEMENT,

INCLUDING REQUIREMENTS SPECIFICATION,

BE ADAPTED, ENHANCED, OR MODIFIED

TO BUILD FUTURE PLANNING AND SCHEDULING SYSTEMS

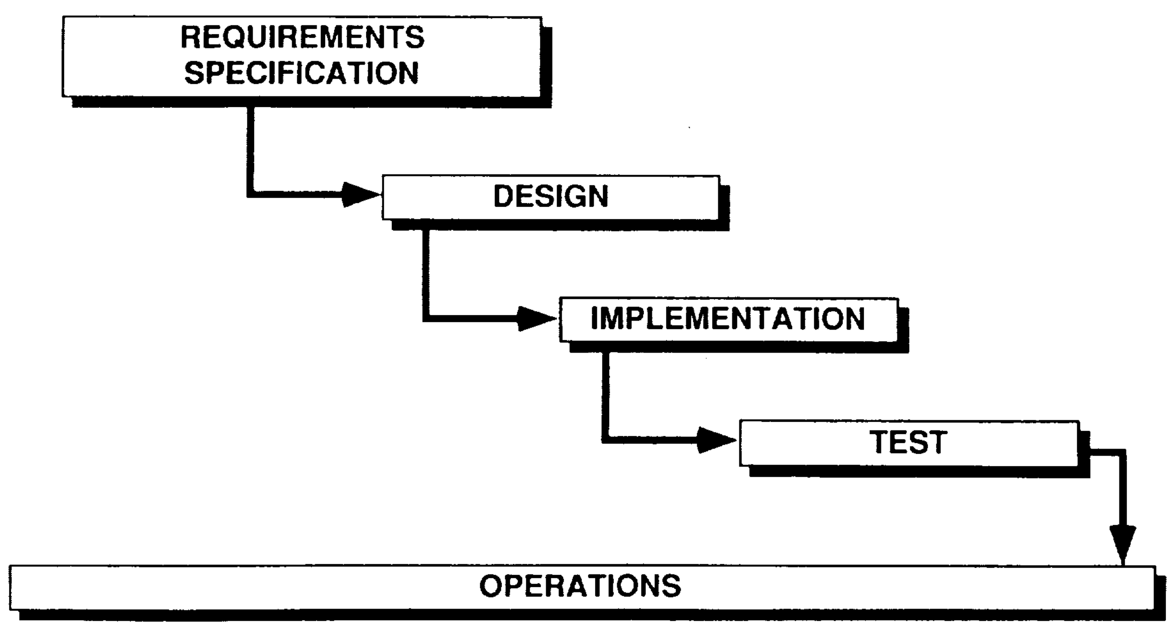
THAT POSSESS LIFECYCLE EFFECTIVENESS?

E-3

-3-

## DISSECTING THE MANAGEMENT CHALLENGE

### TRADITIONAL SYSTEMS ENGINEERING MANAGEMENT PROCESS



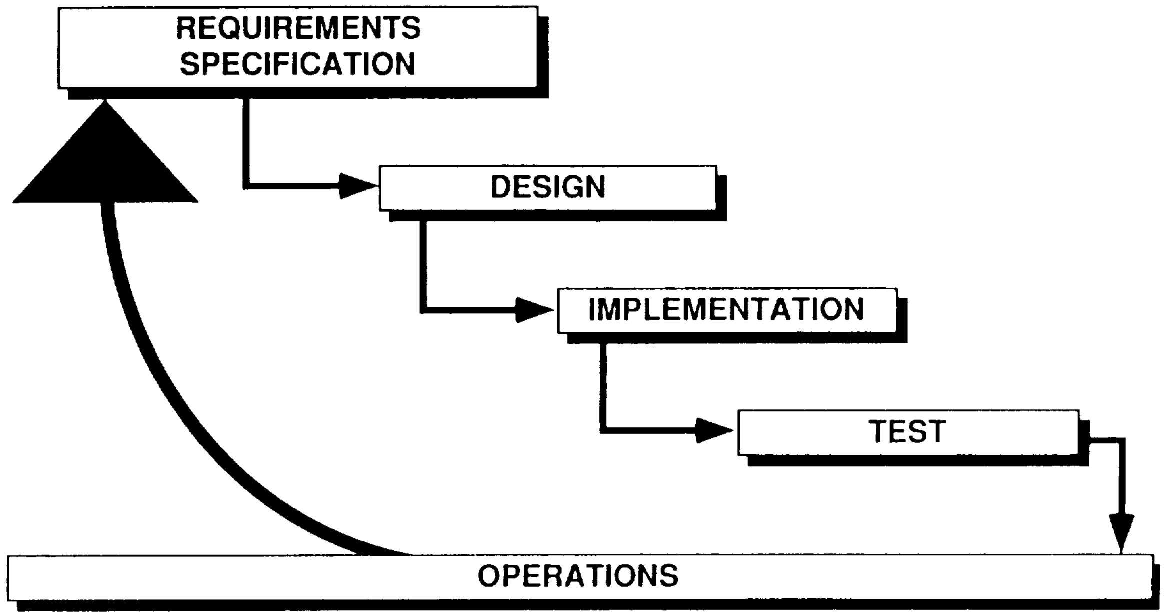



E-4

-4-

# DISSECTING THE MANAGEMENT CHALLENGE

## REDESIGNING THE SYSTEM BASED ON OPERATIONAL EXPERIENCE

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E-5

# DISSECTING THE MANAGEMENT CHALLENGE

## PLANNING AND SCHEDULING SYSTEMS

ANY HUMAN-COMPUTER DECISION-SUPPORT SYSTEM THAT DETERMINES AND / OR REDETERMINES HOW SHARED RESOURCES WILL BE MANAGED OVER TIME

RESOURCES

- ON-ORBIT
  - SPACECRAFT
  - PLATFORMS
  - INSTRUMENTS
  - EXPERIMENTS
  - ASTRONAUTS
- LAUNCHES
  - LAUNCH PADS
  - LAUNCH VEHICLES
  - PAYLOADS
- COMMUNICATIONS
- GROUND
  - FACILITIES
  - COMPUTERS
  - ANTENNAS
  - OPERATORS

DECISIONS

TO ASSURE ACCESS TO RESOURCES CONSISTENT WITH PROGRAM OBJECTIVES

OBJECTIVES

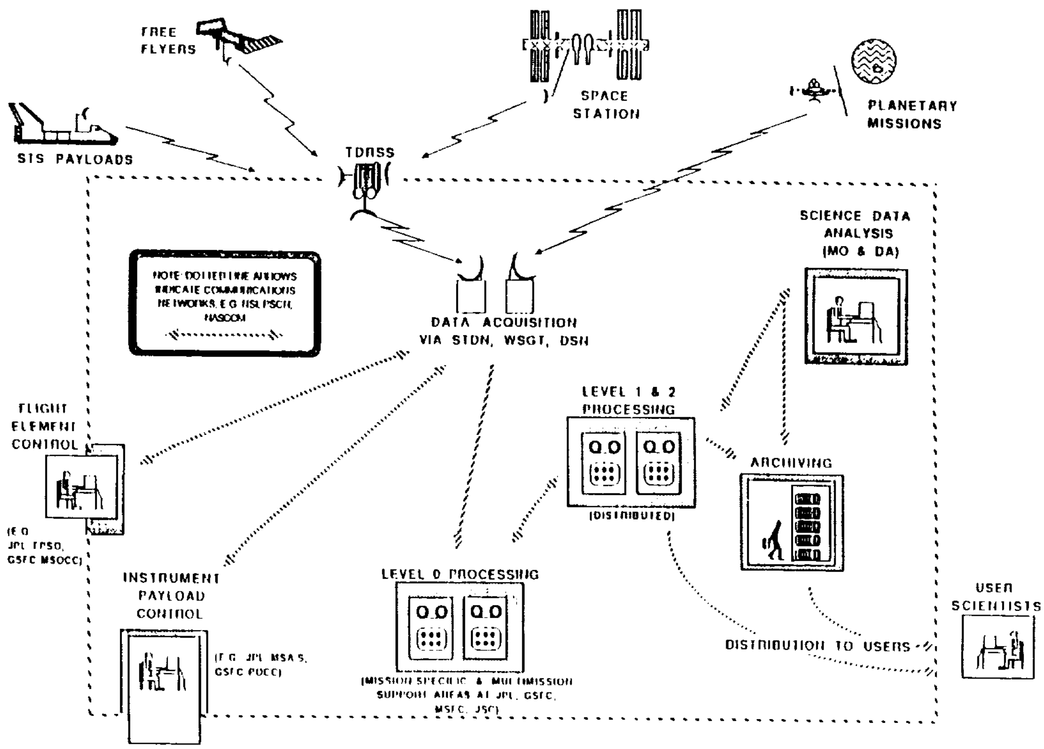
- ACCURATE AND TIMELY ASSIGNMENTS (AND REASSIGNMENTS) OF RESOURCES
- IDENTIFICATION, AVOIDANCE, AND / OR RESOLUTION OF CONFLICTS
- EFFECTIVE AND COMPLEMENTARY HUMAN / COMPUTER INTERACTION
- UNCOMPLICATED AND STRAIGHT FORWARD HUMAN / HUMAN INTERFACE

-6-

E-6

# DISSECTING THE MANAGEMENT CHALLENGE

## SPACE OPERATIONS






# DISSECTING THE MANAGEMENT CHALLENGE

## LIFECYCLE EFFECTIVENESS

## *OPERATIONAL EFFECTIVENESS*

DOING THE RIGHT JOB EFFICIENTLY

## *EXTENSIBILITY*

EASY ACCOMMODATION OF CHANGE

## RESPONDING TO THE MANAGEMENT CHALLENGE

### ADAPTATIONS TO THE TRADITIONAL PRACTICE OF SYSTEMS ENGINEERING MANAGEMENT

*FOR DOING THE RIGHT JOB EFFICIENTLY*

FOCUS SYSTEMS ENGINEERING EFFORT ON DEFINING AND BUILDING THE RIGHT SYSTEM, RATHER THAN ON DEFINING AND FOLLOWING THE RIGHT PROCESS

KEY TO BUILDING THE RIGHT SYSTEM LIES IN DETERMINING AND IMPLEMENTING THE RIGHT REQUIREMENTS IN THE APPROPRIATE OPERATIONS CONTEXT

10 ADAPTATIONS ARE RECOMMENDED

FEATURED ARE:

- REQUIREMENTS AND OPERATIONS CONCEPTS VALIDATION
- PROTOTYPING
- OPERATIONS CONSIDERATIONS AS EVALUATION CRITERIA

9

## RESPONDING TO THE MANAGEMENT CHALLENGE

### ADAPTATIONS FOR DOING THE RIGHT JOB EFFICIENTLY

1. ESTABLISH AND MAINTAIN COMPETING ALTERNATIVE OPERATIONAL CONCEPTS
2. ADD OPERATIONAL EFFECTIVENESS CRITERIA TO THE EVALUATION PROCESS USED IN REQUIREMENTS AND DESIGN REVIEWS
3. START WITH GENERAL FUNCTIONAL REQUIREMENTS AS A BASELINE
4. ADD OPERATIONAL EFFECTIVENESS TO CRITERIA FOR DESIGN ACCEPTABILITY
5. UTILIZE FORMAL PROTOTYPING PLAN FOR CONTROL DURING SYSTEM DEVELOPMENT
6. USE WORKING SOFTWARE AS DETAILED DESIGN DOCUMENTATION
7. DEVELOP A TECHNIQUE FOR MAKING DECISIONS TO BORROW TOOLS, APPROACHES, OR SOFTWARE VS. BUILDING TOOLS, APPROACHES, OR SOFTWARE
8. ENFORCE AN END-TO-END IMPLEMENTATION STRATEGY – IMPLEMENT IN LAYERS NOT SEGMENTS
9. FORMALLY ESTABLISH OPERATIONAL EFFECTIVENESS AS A TEST CRITERION
10. DEVISE TEST PLANS WHICH CERTIFY OPERATIONAL EFFECTIVENESS IN REAL OR SIMULATED OPERATIONAL ENVIRONMENTS

-10

I-10

## RESPONDING TO THE MANAGEMENT CHALLENGE

### ADAPTATIONS TO THE TRADITIONAL PRACTICE OF SYSTEMS ENGINEERING MANAGEMENT

*FOR EASY ACCOMMODATION OF CHANGE*

ELEVATE REQUIREMENTS SPECIFICATION FROM INDIVIDUAL SYSTEM LEVEL TO CLASS LEVEL

- REQUIREMENTS AT THIS LEVEL CAN BE PRECISE AND UNAMBIGUOUS
- GENERAL ARCHITECTURE EXISTS AT THIS LEVEL TO INCORPORATE NEW REQUIREMENTS

RECOGNIZE GENERAL CASE / SPECIAL CASE RELATIONSHIPS AND DESIGN FOR GENERAL CASE

5 ADAPTATIONS ARE RECOMMENDED

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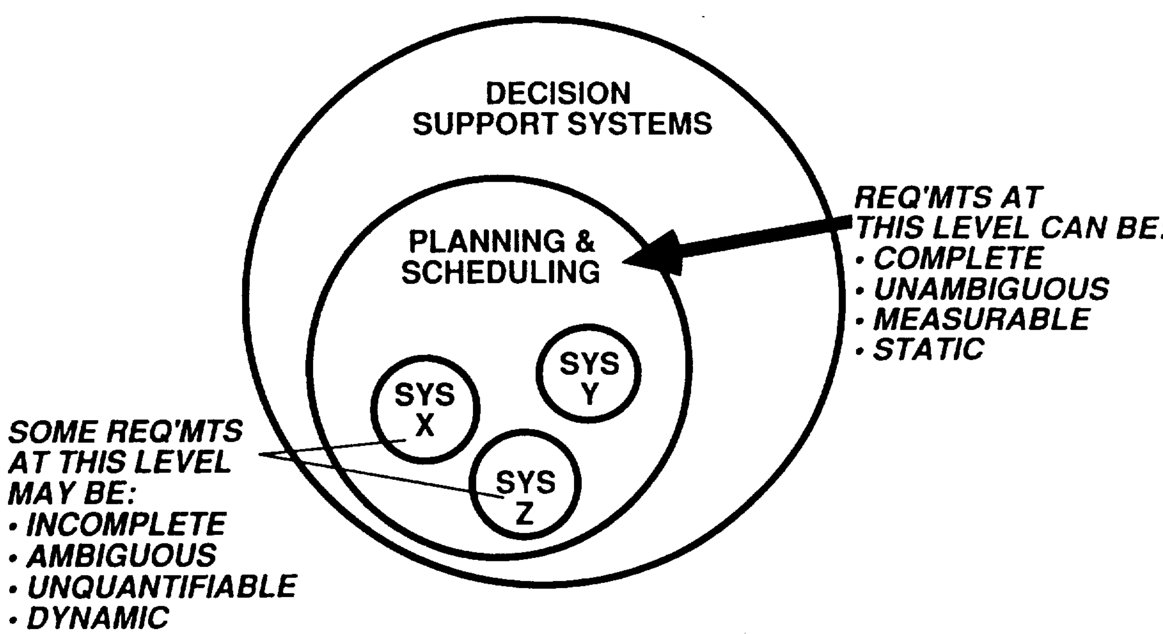
E-11

## RESPONDING TO THE MANAGEMENT CHALLENGE

### REQUIREMENTS SPECIFIED AT THE CLASS LEVEL



## RESPONDING TO THE MANAGEMENT CHALLENGE

### REQUIREMENTS NEED TO BE ELEVATED

TRANSITION TO A GENERALIZED DESCRIPTION OF PLANNING AND SCHEDULING

| FROM | TO |
|---|---|
| • CREWTIME, POWER, WATER | • RESOURCES |
| • EXPERIMENT PERFORMANCE | • ACTIVITIES |
| • SLEEP/ EAT CYCLES | • GENERAL TEMPORAL RELATIONS |
| INDIVIDUAL SYSTEM LEVEL | PLANNING & SCHEDULING CLASS LEVEL |

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E-13

## RESPONDING TO THE MANAGEMENT CHALLENGE

### ADAPTATIONS FOR EASY ACCOMMODATION OF CHANGE

1. CHOOSE TOOLS THAT ARE DATA AND RULE-DRIVEN
2. INCLUDE CODE STRUCTURE ASSESSMENTS AS A FORMAL PART OF DESIGN REVIEWS – FIND MODULES WITH SIMILAR FUNCTIONALITY AND GENERALIZE TO ELIMINATE "DUPLICATES"
3. REVIEW DESIGNS FOR INTERPRETATIONS OF REQUIREMENTS THAT UNNECESSARILY LIMIT ENHANCEMENTS OR EXTENSIONS
4. PERMIT MACHINE DEPENDENCY ONLY WHEN STRONGLY JUSTIFIED
5. DEVELOP AN EVOLUTIONARY ACQUISITION STRATEGY DESIGNED FOR MULTIPLE CYCLES OF DESIGN AND IMPLEMENTATION

# RESPONDING TO THE MANAGEMENT CHALLENGE

## RETROSPECTIVE ASSESSMENT OF HOW ADAPTATIONS WERE UTILIZED

| | ADAPTATIONS TO ACHIEVE OPERATIONAL EFFECTIVENESS | BFG | ESP | RALPH |
|---|---|---|---|---|
| 1 | COMPETING OPS CONCEPTS | ○ | UNK | ● |
| 2 | USE OF GENERAL REQUIREMENTS | ◐ | ◐ | ◐ |
| 3 | OPS EFFECTIVENESS CRITERIA IN SRR | ● | UNK | ◐ |
| 4 | OPS EFFECTIVENESS CRITERIA IN PDR, CDR | ● | UNK | ◐ |
| 5 | PROTOTYPING PLAN | ◐ | ◐ | ● |
| 6 | WORKING SOFTWARE AS SPECIFICATION | ● | UNK | ◐ |
| 7 | BUILD vs BORROW CRITERIA | ○ | UNK | ◐ |
| 8 | END-TO-END IMP STRATEGY | ● | ◐ | ● |
| 9 | OPS EFFECTIVENESS AS TEST CRITERIA | ● | UNK | ○ |
| 10 | TEST IN OPERATIONAL ENVIRONMENT | ● | ◐ | ● |
| | **ADAPTATIONS TO ACHIEVE EXTENSIBILITY** | **BFG** | **ESP** | **RALPH** |
| 1 | DATA- AND RULE-DRIVEN | ● | ○ | ● |
| 2 | CODE STRUCTURE ASSESSMENTS | ● | UNK | ● |
| 3 | PERFORMANCE LIMITATION REVIEWS | ● | ○ | ● |
| 4 | MACHINE INDEPENDENCE | ◐ | ◐ | ◐ |
| 5 | EVOLUTIONARY ACQUISITION | ● | ◐ | ● |

KEY: ● USED ◐ PARTIALLY USED ○ NOT USED

| | | | |
|---|---|---|---|
| EVALUATION BASED ON OPERATIONAL EFFECTIVENESS | HIGH | MODERATE | HIGH |
| EVALUATION SYSTEM BASED ON EXTENSIBILITY | HIGH | LOW | HIGH |



# FOCUSING THE TECHNICAL PERSPECTIVE

## ADAPTATIONS FOR DOING THE RIGHT JOB EFFICIENTLY

1. ESTABLISH AND MAINTAIN COMPETING ALTERNATIVE OPERATIONAL CONCEPTS
2. ADD OPERATIONAL EFFECTIVENESS CRITERIA TO THE EVALUATION PROCESS USED IN REQUIREMENTS AND DESIGN REVIEWS
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4. PERMIT MACHINE DEPENDENCY ONLY WHEN STRONGLY JUSTIFIED

5. DEVELOP AN EVOLUTIONARY ACQUISITION STRATEGY DESIGNED FOR MULTIPLE CYCLES OF DESIGN AND IMPLEMENTATION



# SUMMARY

- TRADITIONAL PRACTICE OF SYSTEMS ENGINEERING MANAGEMENT ASSUMES REQUIREMENTS CAN BE PRECISELY DETERMINED AND UNAMBIGUOUSLY DEFINED PRIOR TO SYSTEM DESIGN AND IMPLEMENTATION; PRACTICE FURTHER ASSUMES REQUIREMENTS ARE HELD STATIC DURING IMPLEMENTATION

- HUMAN-COMPUTER / DECISION SUPPORT SYSTEMS FOR SERVICE PLANNING AND SCHEDULING APPLICATIONS DO NOT CONFORM WELL TO THESE ASSUMPTIONS

  ADAPTATIONS TO THE TRADITIONAL PRACTICE OF SYSTEMS ENGINEERING MANAGEMENT ARE REQUIRED
  - FOR OPERATIONAL EFFECTIVENESS: DOING THE RIGHT JOB EFFICIENTLY
  - FOR EXTENSIBILITY: EASY ACCOMMODATION OF CHANGE

- BASIC TECHNOLOGY EXISTS TO SUPPORT THESE ADAPTATIONS

- ADDITIONAL INNOVATIONS MUST BE ENCOURAGED AND NURTURED

- CONTINUED PARTNERSHIP BETWEEN THE PROGRAMMATIC AND TECHNICAL PERSPECTIVE ASSURES PROPER BALANCE OF THE IMPOSSIBLE WITH THE POSSIBLE

## PRESENTATION OUTLINE

*PART I: A PROGRAMMATIC PERSPECTIVE*

- STATING THE MANAGEMENT CHALLENGE
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*PART II: A TECHNICAL PERSPECTIVE*

- REQUIREMENTS THAT ARE UNLIKE OTHER SYSTEMS
- GOOD AND BAD STARTING POINTS FOR THE DESIGN
- PROJECTING THE CONSEQUENCES OF OPERATIONS CONCEPTS
- SUMMARY



## REQUIREMENTS THAT ARE UNLIKE OTHER SYSTEMS

*CHARACTERISTIC:* THE MERIT OF A PLAN IS DIFFICULT TO QUANTIFY; PLANS USUALLY REPRESENT "ACCEPTABLE COMPROMISES"

*QUANTIFIABLE:*

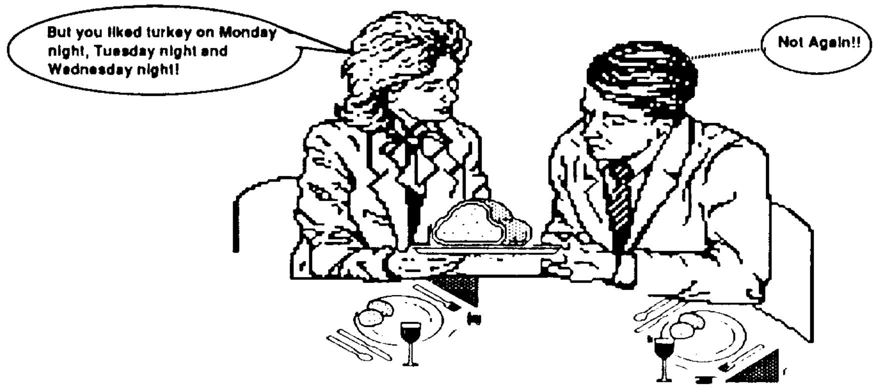
MAX P = f (START TIME, RESOURCE UTILIZATION, SATISFIED REQUESTS)

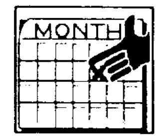
*NON-QUANTIFIABLE:*

- JOE LIKES IT AND HE USED TO DO THE PLANNING
- EVERYBODY CAN LIVE WITH IT
- IT'S OK IF NEXT WEEK THE OTHER USERS CAN HAVE . . . .

## REQUIREMENTS THAT ARE UNLIKE OTHER SYSTEMS

*CHARACTERISTIC:* THE MERIT OF A PLAN IS DYNAMIC



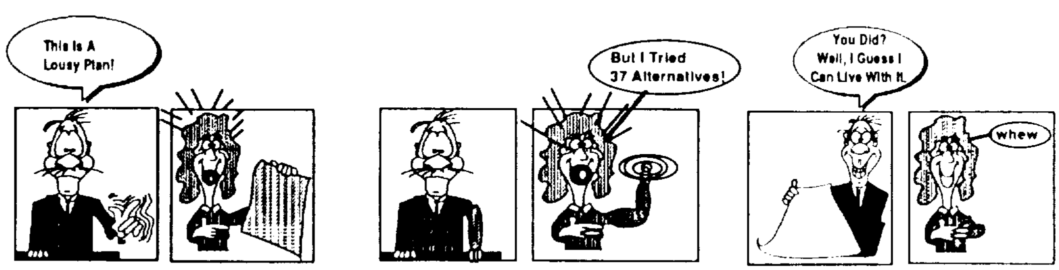

- CIRCUMSTANCES CHANGE

- MERIT MIGHT BE FUNCTION OF HOW THE PLANS LOOK OVER SEVERAL PLANNING HORIZONS



## REQUIREMENTS THAT ARE UNLIKE OTHER SYSTEMS

*CHARACTERISTIC:* THE MERIT OF PLAN IS DEPENDENT ON <u>THE PROCESS</u> USED TO GENERATE IT.



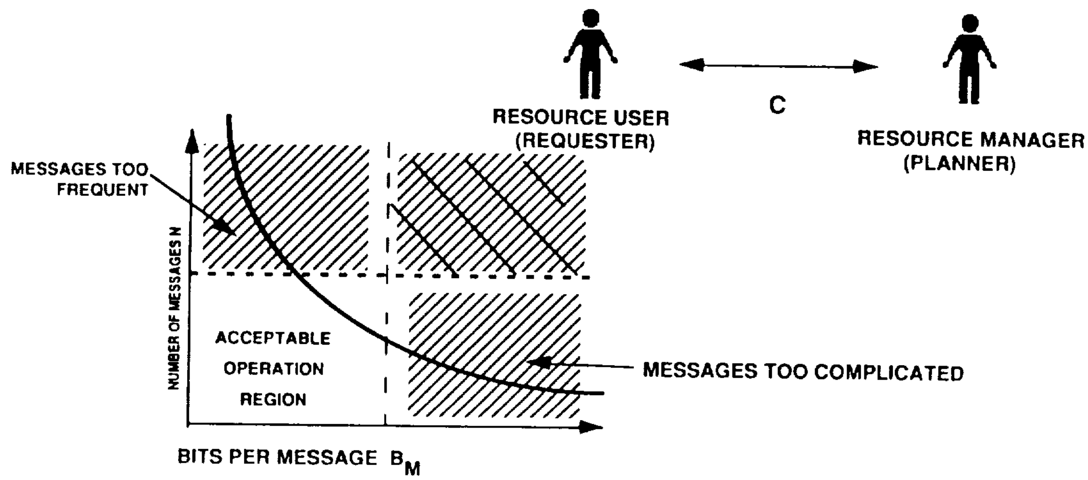

NO INFORMATION ABOUT PROCESS | PROCESS INFORMATION PROVIDED | MERIT OF THE PLAN "CHANGES"

- SAME PLAN LOOKS GOOD OR BAD DEPENDING ON NUMBER OF ALTERNATIVES EXAMINED
- MERIT OF PLAN CANNOT BE DETERMINED FROM THE INFORMATION IN THAT PLAN
- MERIT IS <u>PROCESS</u> NOT <u>PRODUCT</u> DEPENDENT
- THIS CHARACTERISTIC IS FUNDAMENTALLY AND CRITICALLY DIFFERENT FROM ENGINEERING SYSTEMS

## REQUIREMENTS THAT ARE UNLIKE OTHER SYSTEMS

*CHARACTERISTIC:* THE INFORMATION FLOW CONTENT BETWEEN SERVICE REQUESTER AND THE PLANNER ARE VERY DIFFICULT TO PREDICT

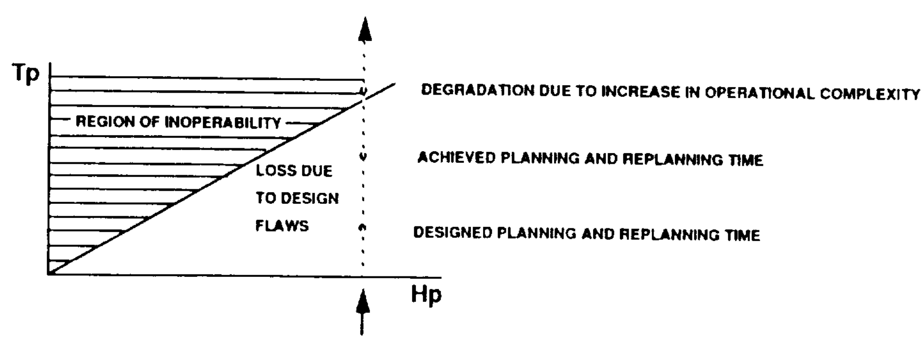
LET C BE THE TOTAL INFORMATION (IN BITS) NEEDED TO RESOLVE THE RESOURCE ALLOCATION; THEN $N \times B_M = C$.






## REQUIREMENTS THAT ARE UNLIKE OTHER SYSTEMS

*CHARACTERISTIC:* THE TIME REQUIRED TO BUILD A PLAN IS LONGER THAN ORIGINALLY PREDICTED

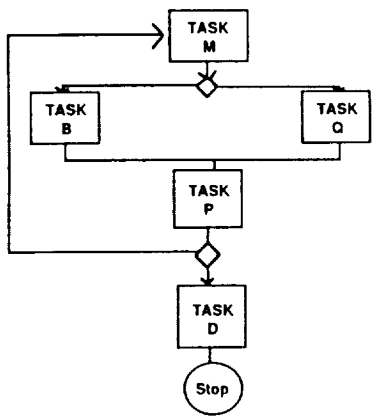



DESIGNED PLANNING HORIZON

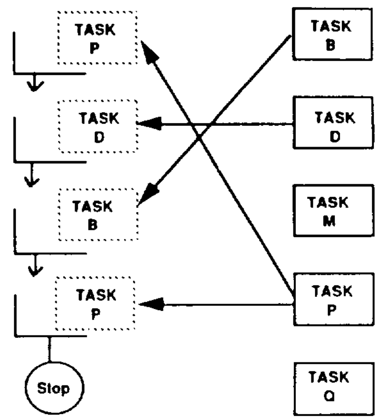
- Tp IS THE TOTAL PLANNING AND REPLANNING TIME IN HORIZON K FOR ACTIVITIES TO OCCUR IN HORIZON K + 1
- Hp IS THE LENGTH OF THE PLANNING HORIZON
- CLEARLY Tp/Hp < 1 TO MAINTAIN OPERATIONS
- WHAT SHOULD BE THE DESIGN VALUE OF Tp/Hp?

## REQUIREMENTS THAT ARE UNLIKE OTHER SYSTEMS

*CHARACTERISTIC:* THE SEQUENCE OF PLANNING TASKS CANNOT BE DETERMINED AT DESIGN TIME




TASK SEQUENCE DETERMINABLE AT DESIGN TIME




TASK SEQUENCE DETERMINABLE AT TASK PERFORMANCE TIME



## GOOD AND BAD STARTING POINTS FOR THE DESIGN

- DESIGN THE SYSTEM AS A *REPLANNING* SYSTEM
  - REPLANNING IS A MORE FREQUENT TASK IN MOST OPERATIONAL ENVIRONMENTS
  - PLANNING CAN BE ACCOMMODATED AS A SPECIAL CASE OF REPLANNING
  - FIRST COME / FIRST SERVED ALLOCATION (i.e., DEMAND ASSIGNMENT) CAN BE ACCOMMODATED AS A SPECIAL CASE OF PLANNING

## GOOD AND BAD STARTING POINTS FOR THE DESIGN

- DESIGN THE SYSTEM INITIALLY TO ALLOW HUMANS TO MAKE ALL DECISIONS
  - ALGORITHMS SHOULD BE DESIGNED TO EMULATE HUMAN DECISION BEHAVIOR
  - ONLY DECISION MAKING THAT IS DETERMINED TO BE ROUTINE SHOULD BE DELEGATED TO THE MACHINE
  - OPERATIONAL EXPERIENCE IS NEEDED TO DETERMINE WHICH DECISIONS ARE ROUTINE

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## GOOD AND BAD STARTING POINTS FOR THE DESIGN

- DESIGN THE SYSTEM ORIGINALLY TO HANDLE POOLED RESOURCES
  - POOLED RESOURCES CAN ACCOMMODATE ANY QUANTITY OF A SHARED RESOURCE
  - INDIVIDUAL RESOURCES CAN BE ACCOMMODATED AS A SPECIAL CASE OF POOLED RESOURCES

## GOOD AND BAD STARTING POINTS FOR THE DESIGN

- DESIGN THE SYSTEM ORIGINALLY TO HANDLE GENERAL TEMPORAL RELATIONSHIPS

  - ACCOMMODATE NUMEROUS SEQUENCE RELATIONSHIPS AS SPECIAL CASES

    -- PREDECESSOR / SUCCESSOR RELATIONSHIPS
    -- MINIMUM SEPARATION
    -- MAXIMUM SEPARATION
    -- MINIMUM OVERLAP
    -- MAXIMUM OVERLAP
    -- SPECIFIED OVERLAP
    -- ONE ACTIVITY ANY TIME DURING ANOTHER

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## PROJECTING THE CONSEQUENCES OF OPERATIONS CONCEPTS

- UNDERSTANDING OUR PROBLEM DOMAIN IS VERY IMPORTANT
  - EXAMPLE: SNC *IS NOT* PRIMARILY
    -- A S/C CONTROL CENTER
    -- A COMMUNICATIONS SYSTEM
    -- A COMMAND AND CONTROL FACILITY

    SNC *IS*
    -- A DECISION SUPPORT SYSTEM
    -- A SERVICE PLANNING CENTER
    -- A SERVICE PROVIDER/FACILITATOR FOR USERS
  - THE RIGHT TECHNIQUES FOR THE WRONG DOMAIN WON'T HELP

- THE DESIGN CONSEQUENCES OF AN OPERATIONS CONCEPT CAN BE PREDICTED
  - SEEMINGLY APPROPRIATE CONCEPTS CAN LEAD TO UNACCEPTABLE COSTS, COMPLEXITIES, etc.
  - A METHODOLOGY FOR PREDICTING THE DESIGN CONSEQUENCES OF AN OPERATIONS CONCEPT HAS BEEN DEVELOPED

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# PREDICTING DESIGNS FROM OPERATIONS CONCEPTS: AN EXAMPLE

OPS CONCEPTS "DIMENSIONS"

- HUMAN/COMPUTER DECISION ROLES
- NUMBER OF USER-TO-SERVICES INTERFACES
- USER-TO-CENTER COMMUNICATION STYLES
- REPLANNING PHILOSOPHY
- REQUEST SATISFACTION GOALS
- USER KNOWLEDGE OF TDRS
- USER KNOWLEDGE OF NETWORK
- SERVICE CONFIRMATION RESPONSE
- RELIABILITY OF SERVICES
- SECURITY OF USERS
- PERCEIVED ABUNDANCE OF RESOURCES
- PERCEIVED COMPLEXITY OF DECISIONS
- DEVELOPMENT vs OPERATIONAL COST TRADEOFFS

ANALYSIS PROCESS

- USE DIGITAL MSG'S FOR COMM
- FAULT ISOLATION IN NCC
- SCHEDULE BY PRIORITY
- FEED SERVICE ACCT'G BACK TO SCHEDULER PERIODICALLY
- .

- USE FAX & E-MAIL FOR COMM
- FAULT ISOLATION IN NCC
- SCHEDULE BY COMBINATION OF CRITERIA
- FEED SERVICE ACCT'G BACK TO SCHEDULER IN SAME PLANNING CYCLE
- .

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# SUMMARY

PAST PROBLEMS HAVE THE FOLLOWING ORIGINS:

- NOT RECOGNIZING THE UNUSUAL AND PERVERSE NATURE OF THE REQUIREMENTS (FOR PLANNING AND SCHEDULING)
- NOT RECOGNIZING THE BEST STARTING POINT ASSUMPTIONS (GENERAL CASES) FOR THE DESIGN
- NOT UNDERSTANDING THE TYPE OF SYSTEM THAT WE'RE BUILDING
- NOT UNDERSTANDING THE DESIGN CONSEQUENCES OF THE OPERATIONS CONCEPT SELECTED

THE GOOD NEWS IS THAT WE:

- NOW HAVE MORE SUCCESSFUL SYSTEMS TO EXAMINE
- NOW HAVE A GOOD COLLECTION OF CLASS-LEVEL REQUIREMENTS
- NOW RECOGNIZE THE GENERAL CASES THAT ACCOMMODATE THE REQUIREMENTS FROM A PARTICULAR DOMAIN AS PARAMETRIC SPECIAL CASES
- NOW CAN BEGIN TO PREDICT THE CONSEQUENCES OF OPS CONCEPT ALTERNATIVES

N92-11043

# Proposed Planning & Scheduling Services for the SNC in the CDOS Era

December 1990

Todd Welden CSC/520





## Agenda

- Introduction
- Proposed SNC data flow for CDOS era customers
- Generic Scheduling Concept
- P&S services SNC could provide in the CDOS era
  - Provide security
  - Maintain a data base
  - Generate universal time interval sets
  - Process queries
  - Process a robust generic request language

# Introduction

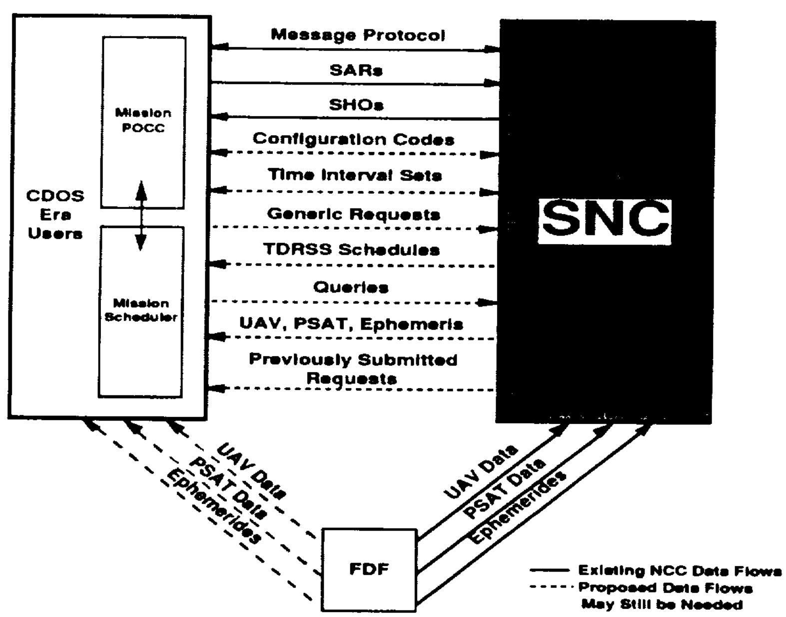
**Motivation for this presentation**

- **Studies indicate that the current NCC mode of operation needs to be enhanced to meet the needs of the mid to late 1990s.**
  - ***CDOS Operations Management Service (COMS) Planning and Scheduling Concept Assessment*** **(DSTL-90-010, CSC/TM-90/6079)**
  - ***EOS Planning/Scheduling/Command Management Study*** **(CSC/TM-90/6054)**
- **There is a need to simplify the request interface for SN services**
  - **More complex missions**
  - **More flexible spacecraft operations**
  - **More scheduling data volume**
  - **Events per spacecraft and scheduling period**





# Proposed SNC data flow for CDOS era customers



## Motivation for Generic Scheduling Use

- Proposed for all missions in the CDOS era, in some form
  - COBE is using a customized "generic" request interface for user requests
  - ERBS is using a customized "generic" request interface for user requests
  - UARS will be using generic scheduling
  - EOS plans to use generic scheduling





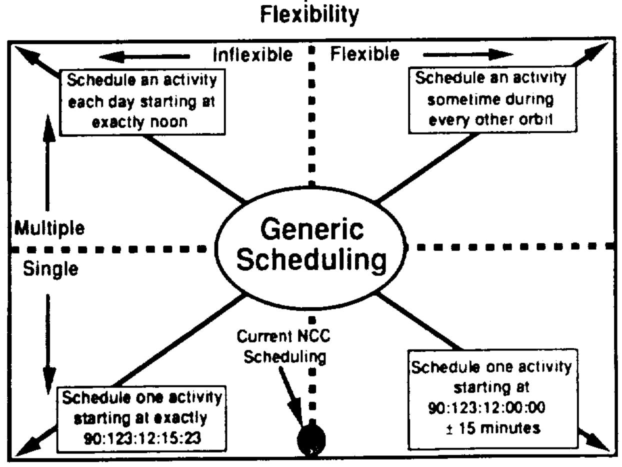
## Generic Scheduling Concept

**Encompasses four major classifications of requests**

Request Flexibility

- Requests for multiple activities with no flexibility
- Requests for multiple activities that are flexible

Number Of Activities Per Request




- Requests for a single activity with no flexibility
- Requests for a single activity that are flexible

## Generic Scheduling

- Generic scheduling is a viable mode of operation for the SNC
  - Supports specific / inflexible requests
  - Allows a great deal of customer flexibility
  - Allows customers to symbolically define and reference constraints
  - Allows the expression of complex relationships
  - Allows single requests for multiple instances of the same activities
  - Allows flexible resource requirements
  - Allows requests with flexible durations
  - Allows the scheduler more flexibility when scheduling
  - Leads to less impact when rescheduling or adding new events





P&S services SNC could provide in the CDOS era

## Provide Security

Motivation:
- Access to mission data must be restricted to only the owner

Service:
- Access to mission data only by owner
- Current NCC restrictions are adequate

P&S services SNC could provide in the CDOS era

## Maintain a Data Base

**Motivation:**

- SNC is always on-line
- Missions require the same type of data maintained by SNC
- Provides a centralized repository for data
- Ensures data compatibility between customers and SNC
- Reduces redundancy of data flows

**Service:**

- Maintain a data base of
  - Configuration codes
  - UAV data
  - PSAT data
  - Ephemeris data
  - Previously submitted requests
  - Time interval sets





P&S services SNC could provide in the CDOS era

## Generate Universal Time Interval Sets

**Motivation:**

- All customers will need the universal time interval sets
- Standardizes format and contents
- Leads to a standardized mode of operation with SNC

**Service:**

- Generate time interval sets from UAV, PSAT, Ephemeris data for:
  - TDRS contacts
  - Orbit starts/stops
  - Spacecraft days/nights

P&S services SNC could provide in the CDOS era

## Process Queries

Motivation:

- Reduces customer and SNC asynchronous data traffic
- Provides customers with correct and current information

Service:

- Send to the customer
  - TDRSS schedules
  - Configuration codes
  - UAV data
  - PSAT data
  - Ephemeris data
  - Previously submitted requests
  - Time interval sets





P&S services SNC could provide in the CDOS era

## Process a Robust Generic Scheduling Language

Motivation:

- Allows all missions to use the same flexible, robust language
- Standardizes the scheduling language and SNC interface
- Most CDOS era missions will have their own scheduler for mission activities
- Leads to standardization of the scheduling engine core
- Leads to a standard scheduling language for
  - Mission scheduling
  - Investigator to mission interface
- Allows customers to specify multiple options for support
- Allows the scheduler flexibility in the scheduling of the requests
- Allows the scheduler to produce a schedule that retains as much of the flexibility as possible based on the final resource usage
- Allows schedule modification with minimal perturbation
- Rescheduling causes less impact and can be mostly automated

P&S services SNC could provide in the CDOS era

## Process a Robust Generic Scheduling Language

Service:

- Allow additions, deletions, and replacements of:
  - Generic and specific requests
  - Individual request instances (events)
  - Pending (i.e. not yet scheduled) events
  - Scheduled events
  - Customer-defined time interval sets
- Allow one generic request to generate multiple events
- Allow flexible time intervals (time tolerance / windows)
- Allow flexible request durations
- Allow preferred and alternate sets of resource requirements
- Allow a "wildcard" TDRS ID and antenna ID

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# An RF Interference Mitigation Methodology with Potential Applications in Scheduling

N92-11044


GSFC
Code 531.1

Yen F. Wong
James L. Rash


December 12, 1990

G-1


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An RF Interference Mitigation Methodology with Potential Applications in Scheduling


## Agenda

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## An RF Interference Mitigation Methodology with Potential Applications in Scheduling



- Communications Link Analysis and Simulation System (CLASS)
- Space Network RF Mutual Interference and Scheduling
- RF Interference Mitigation Methodology
- Interference Mitigation Aid for Scheduling
- Numerical Examples
- Conclusions and Future Work

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An RF Interference Mitigation Methodology with Potential Applications in Scheduling

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# CLASS

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# Communications Link Analysis & Simulation System (CLASS)

GSFC

- Unique software tool for the prediction and evaluation of TDRSS/user spacecraft communications link performance.
- End-to-end modeling of Space and Ground Networks, channel environment, and user spacecraft communications systems.
- All communications channel parameters that affect link performance, including interference, are maintained in CLASS data bases.
- Developed by NASA Goddard Space Flight Center (GSFC) Code 531.

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# CLASS Interference Analysis and Mitigation Tools

GSFC

- Interference analysis and mitigation tools have been developed in the CLASS environment for use in:
  - -- communications performance evaluation
  - -- mission planning
- Potential applications in:
  - -- analysis, evaluation, and optimization of user schedules

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# Space Network RF Mutual Interference and Scheduling





## Space Network RF Mutual Interference and Scheduling



- Increasingly competitive climate for scheduling of Space Network resources in the Space Station era.
- Potential RF mutual interference warrants increasing concern in terms of efficiency in network resource allocation and scheduling.
- Scheduling efficiency of current network operations system could be enhanced through consideration of communications performance in mutual interference mitigation.
- CLASS interference analysis tools can be used in efforts to enhance network scheduling efficiency.

## Interference Mitigation Methodology

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## Interference Mitigation Methodology



- **STEP 1**

**For every given pair of desired and interfering signals, determine the discrimination required to guarantee nonnegative BER link margin.**

## Interference Mitigation Methodology

- **Required discrimination**

$$\delta = \left(\frac{S}{I}\right)_{required} - \left(\frac{S}{I}\right)_{worst}$$

**"Required S/I" is the value of S/I such that the degradation of the desired user's signal equals its worst case channel margin. The worst case channel margin is a parameter that characterizes the desired user's link performance.**

**"Worst S/I" is determined by formulating S/I as a function of the separation angle between interferer and desired user. "Worst S/I" designates the global minimum of this function.**





## Interference Mitigation Methodology

- **The signal to interference level ratio S/I in dB at TDRS is defined as a function of the separation angle $\alpha$ between the desired user and the interferer as seen from TDRS:**

$$\frac{S}{I}(\alpha) = (P_d + G(0)) - (P_i + G(\alpha) + R(\alpha)) + G_p + A_p + L_{fs}$$

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## Interference Mitigation Methodology

Pd = the worst case (maximum range) TDRS received power at unity antenna gain for the desired user (dB) including the loss due to the nonperfect polarization match between the TDRS and desired user antennas. It is assumed that the desired user is on the TDRS antenna boresight and that the desired user antenna is pointing toward TDRS. Pd includes contributions from stochastic sources such as multipath (vehicle, earth, and atmospheric) and RFI.

Pi = the best case (minimum range) TDRS received power at unity antenna gain for the interferer (dB).

G = the TDRS antenna gain (dB) as a function of the angle alpha.

R = the polarization rejection of the interferer signal at the oppositely polarized TDRS antenna (dB) as a function of the angle alpha. The value of R is always negative when rejection is present.

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## Interference Mitigation Methodology

Gp = 10 * ALOG10 (Desired user PN chip rate/Desired channel symbol rate) is the processing gain (in dB) of the PN spread signal

Ap = 10 * ALOG10 (Interferer channel PN chip rate/Desired channel symbol rate) is the reduction factor (in dB) if the interferer is PN spread when the desired channel is not PN spread.

Lfs = reduction of interferer power due to frequency separation.

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## Interference Mitigation Methodology

- **Step 2**

**For every given pair of desired and interfering signals, calculate the required separation angle (the largest separation angle between the desired user and interferer that provides the required discrimination as determined in Step 1).**

**This calculation utilizes the TDRS antenna gain pattern, adjusted as necessary to reflect polarization rejection of the interferer signal.**

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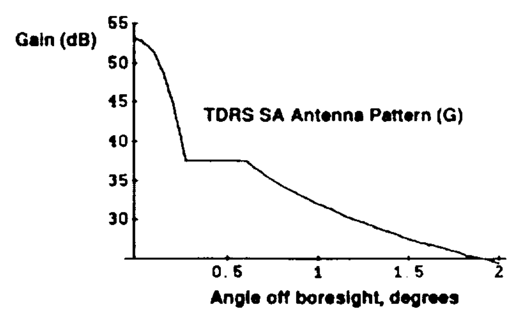
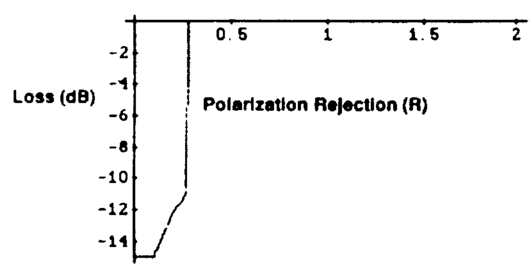
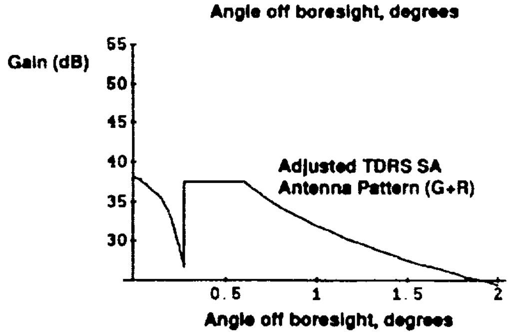
## Adjusted Antenna Gain Pattern (Example)




Polarization rejection modeled as a function of angle off boresight at the TDRS SA antenna when the transmitting antenna is that of the Space Station Manned Base.




$$\textit{required discrimination}\ \delta = -\Delta(G+R)$$

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## Interference Mitigation Methodology

- **Step 3**

**Based on the separation angles obtained in step (2), find all potential interference intervals.**

**A potential interference interval is defined as any time interval during which the separation angle between the two spacecraft is less than the required separation angle.**

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## An RF Interference Mitigation Methodology with Potential Applications in Scheduling

# Interference Mitigation Aid for Scheduling

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# An Approach to Interference Mitigation Scheduling

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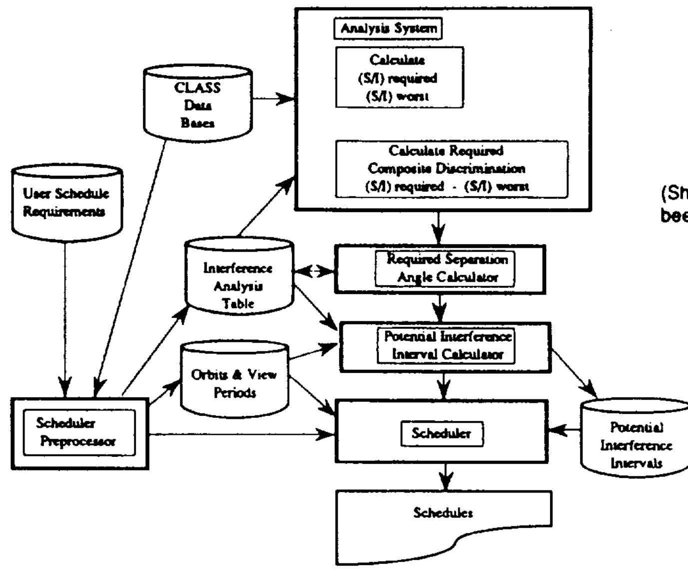
Block Diagram




(Shaded blocks have been implemented.)

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# An RF Interference Mitigation Methodology with Potential Applications in Scheduling

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## Numerical Example

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## Numerical Example

- These missions operate at Ku band with carrier frequency equal to 15.0034 GHz, unspread.
  - -- Space Station Manned Base (SSMB) versus Space Shuttle Orbiter (SSO)
  - -- Earth Observing System (EOS) versus Space Shuttle Orbiter (SSO)

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## Numerical Example (continued) -- SSO Link Characteristics

SSO operates with Right Circular Polarization (RCP). Link characteristics are as follows:

| CHANNEL | DATA RATE (kbps) | EIRP (dBW) | LINK MARGIN (dB) |
|---|---|---|---|
| Channel 1: Subcarrier Q | 192 | 39.4 | 19.0 |
| Channel 2: Subcarrier I | 2,000 | 43.6 | 13.5 |
| Channel 3: Baseband | 50,000 | 51.0 | 1.5 |

Channels 1 and 2 are rate 1/2 convolutional coded. Channel 3 is uncoded.

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## Numerical Example (continued) -- SSMB Link Characteristics

SSMB operates with Left Circular Polarization (LCP) at data rates of 300 Mbps and 50 Mbps.

| CHANNEL | DATA RATE (Mbps) | EIRP (dBW) | LINK MARGIN (dB) |
|---|---|---|---|
| I | 150 | 57.1 | 3.0 |
| Q | 150 | 57.1 | 3.0 |
| I | 25 | 57.1 | 10.8 |
| Q | 25 | 57.1 | 10.8 |

The parameters given above for SSMB are preliminary and subject to change.

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## Numerical Example (continued) -- EOS Link Characteristics

EOS operates with RCP at a data rate of 300 Mbps.

| CHANNEL | DATA RATE (Mbps) | EIRP (dBW) | LINK MARGIN (dB) |
|---|---|---|---|
| I | 150 | 57.6 | 3.6 |
| Q | 150 | 57.6 | 3.6 |

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## Numerical Example (continued) --Interference Analysis Results

There is no unacceptable interference between the EOS 300 Mbps link and the SSO channels 1 and 2.

There is no unacceptable interference between the SSMB 300 Mbps link and the SSO channels 1, 2, and 3.

| | | Case 1 | Case 2 |
|---|---|---|---|
| Desired User | User ID | SSO | SSO |
| | Channel | 3 | 3 |
| | Polarization | RHC | RHC |
| | Worst Case Margin (dB) | 1.5 | 1.5 |
| Interferer | User ID | EOS | SSMB |
| | Polarization | RHC | LHC |
| | Axial Ratio (dB) | 1.5 | 2.1 |
| S/I | Required (dB) | 6.2 ** | 9.0** |
| | Boresight (dB) | -11.6 | 4.0 |
| | Worst Case (dB) | -11.6 | 4.0 |
| Required Discrimination (dB) | | 17.8 | 5.0 |
| Required Separation Angle (deg) | | 0.74 | 0.92 |

** Note: CLASS simulation result.

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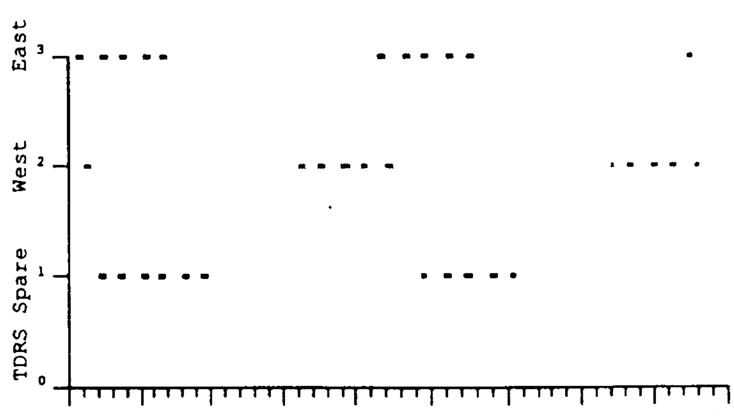
## Numerical Example (continued) --Potential Interference Intervals




Assumes the users (SSO and SSMB) have identical orbits except for a 20 degree difference in orbital phasing.

During the 24 hour period, potential interference exists for a total of approximately 20 minutes for each TDRS.

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## Conclusions and Future Work

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## Conclusions and Future Work

- Tools for interference analysis and mitigation have been developed in the CLASS environment for:
  - -- communications performance evaluation
  - -- mission planning
- Potential applications are seen in:
  - -- analysis, evaluation, and optimization of user schedules
- Tools producing "required separation angles" and "potential interference intervals" can be used as an aid to mutual interference mitigation within a scheduling system.
- Possible future consideration of multiple interferers.

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N92-11045

# AUTOMATED CONFLICT RESOLUTION ISSUES

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## INTRODUCTION

Purpose:

- To initiate discussion of how conflicts for Space Network resources should be resolved in the ATDRSS era.

Topics:

- Describe how resource conflicts are currently resolved.
- Describe issues associated with automated conflict resolution.
- Present conflict resolution strategies.
- Suggest discussion topics.

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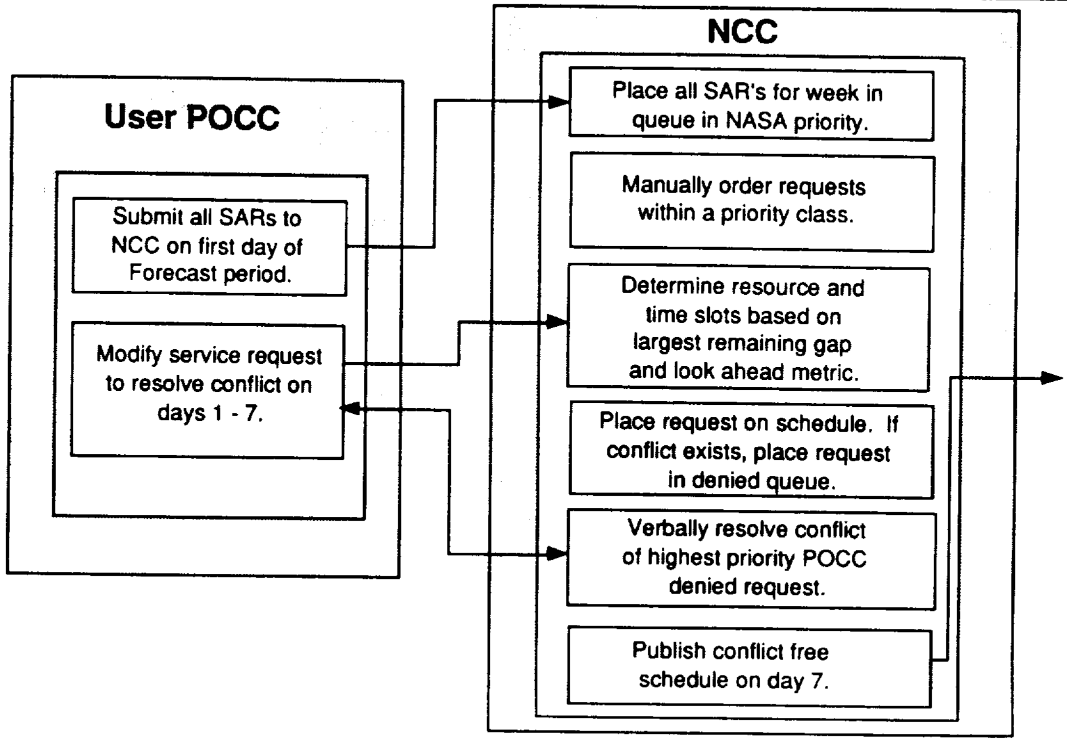
# CURRENT SN CONFLICT RESOLUTION

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# CURRENT OPERATIONAL LIMITATIONS

**Current conflict negotiation is a verbal, time consuming process between Forecast Analysts and user POCCs.**

**Security prohibits POCCs from accessing entire schedule.**

**Forecast Analyst lacks automated scheduling tools and user knowledge.**

**Current SN service requests do not utilize POCC tolerance.**

- Requests allow specifying plus or minus time tolerance.
- Configuration codes may indicate "open selection" for antenna and interface channel.



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## CURRENT SOFTWARE LIMITATIONS

**Current NCC scheduler emphasizes conflict avoidance, rather than conflict resolution.**

- Events scheduled to avoid potential conflicts.
    - Leave largest gap of unscheduled time
    - Look-ahead metric schedules event to avoid conflict with remaining events.

**No knowledge of the applicability or preference of individual conflict resolution strategies.**

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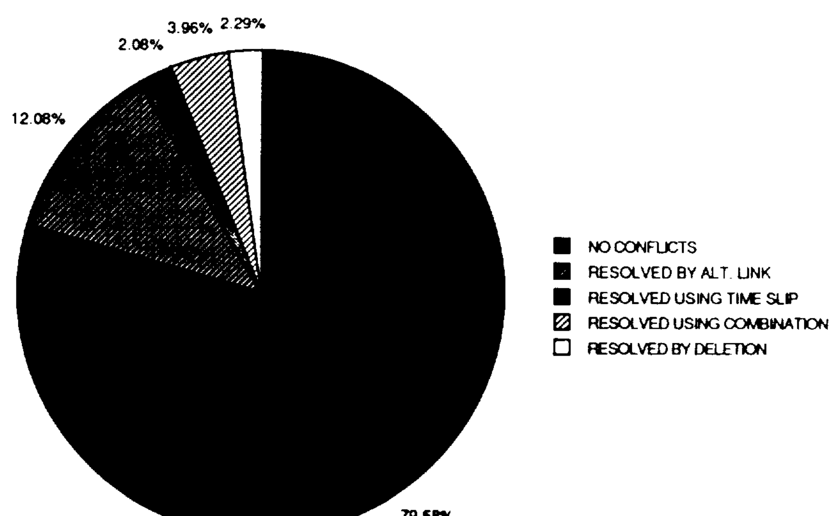
## CURRENT CONFLICT RESOLUTION




**The fact that ninety percent of the conflicts were resolved indicates that user flexibility exists.**



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## ATDRSS ERA CONFLICT RESOLUTION

**ATDRSS era service requests will increase three to ten fold.**

**Manual conflict resolution will cause unacceptable response times and life cycle costs.**

**Automated conflict resolution requires knowledge:**

- Embedded in the SNC scheduling system.
- Identified by the user POCC in each specific service request

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## EMBEDDED KNOWLEDGE

**Knowledge requirements:**

- **User capabilities**
- **User preferences**
- **SN resource data**

**Conflict resolution profile created for each user POCC**

- **Hierarchy of conflict resolution strategies**
- **Service parameter tolerances and dependencies**

**SNC generated alternatives approved by the user POCC.**



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## USER SPECIFIED KNOWLEDGE

**Include knowledge in the user POCC service request.**

**Prioritize request tolerances and alternatives.**

**Information exchange facilitated by implementation of a user Pocc workstation.**

- Graphically display schedule and service flexibility.
- Simultaneously display data at the SNC and POCC.

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## FACTORS INFLUENCING CONFLICT RESOLUTION

**Organizational goals affecting conflict resolution are:**

- **NASA established user POCC priority.**
- **Certain users assigned specific links.**
- **Hold back resources as spares.**
- **Maximize utilization of single resources.**
- **Leveling of resource utilization across the system.**
- **Rewarding cooperation.**

**Operational limitations affecting conflict resolution:**

- **Development (forecast) period.**
- **Maintenance (active) period.**
- **Spacecraft emergencies.**



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## MANUAL CONFLICT RESOLUTION

**Special circumstances will require manual conflict resolution by the SN scheduling analyst.**

- Two POCCs with same priority (Space Station and Space Shuttle) have a resource conflict.
- Spacecraft emergencies conflict with higher priority user POCC services

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## CONFLICT RESOLUTION STRATEGIES

**Potential strategies include:**

- **Priority.**
- **Moving a service in time.**
- **Moving a service to the previous or next valid view period.**
- **Switching to an alternate resource.**
- **Shrinking a service duration.**
- **Breaking up a prototype event into individual services, and performing separate conflict resolution strategies on the individual services.**
- **Breaking up a service into multiple discontinuous services, or gapping.**
- **Combinations of the above strategies.**
- **Deleting a service from the schedule.**

# DISCUSSION TOPICS

- What specific conflict resolution strategies are applicable to the user POCCs?
- How much would conflict resolution strategies and preferences vary between services of a specific user POCC?
- How much would conflict resolution strategies and preferences vary between different user POCCs?
- Does a hierarchy of strategy preferences exist?
- Under what circumstances should manual conflict resolution be required?
- How amenable to automatic conflict resolution are user POCCs?
- How much and what type of tolerance could be communicated to the NCC from user POCCs?
- How much would tolerances vary between services of a specific user POCC?

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N92-11046

# Effect of Locus of Resource Control on Operational Efficiency in Distributed Operations

A. L. Geoffroy
Martin Marietta Information & Communication Systems
(303) 977-8186

Space Network Control Workshop,
Goddard Space Flight Center
Dec. 12&13, 1990

MARTIN MARIETTA

I-1

## OVERVIEW

PROBLEM

- SNC FROM THE CUSTOMER'S PERSPECTIVE
- REQUIREMENTS FOR COORDINATING COMM AND OTHER RESOURCES

LOCUS OF CONTROL IN DISTRIBUTED OPERATIONS

- DIFFERENT WAYS TO DISTRIBUTE CONTROL

EFFICIENCY

- GENERAL CONSIDERATIONS
- EFFICIENCY EFFECTS DEPENDING ON CONTROL DISTRIBUTION

RECOMMENDATIONS



I-2



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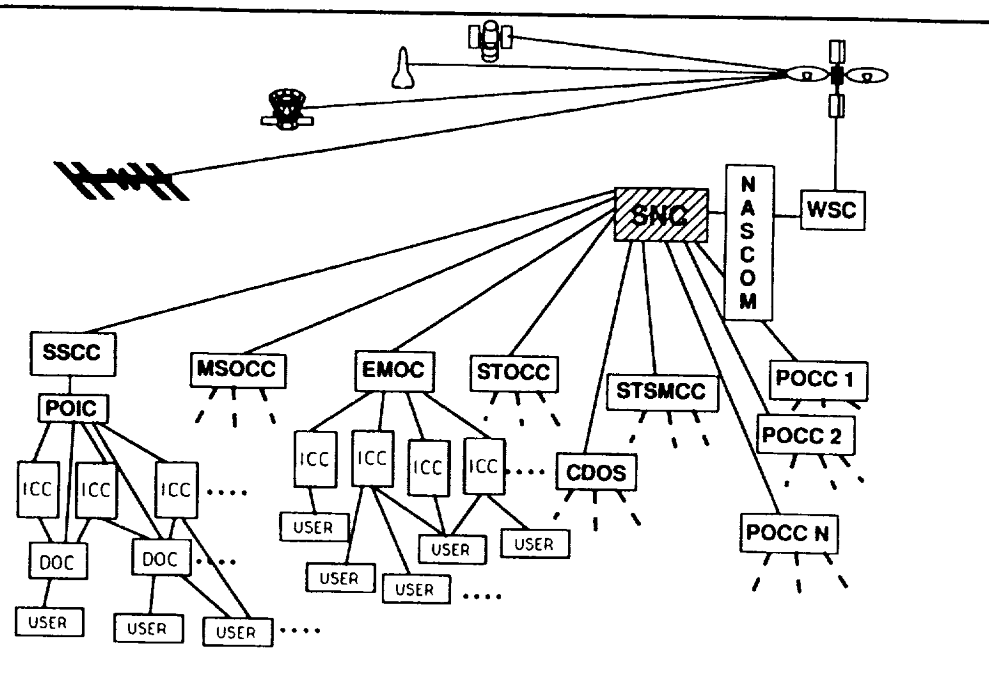
## SNC USAGE IN THE ATDRSS ERA




Space Network Control Workshop,
Goddard Space Flight Center
Dec.12&13, 1990

MARTIN MARIETTA

Locus of Resource Control and Operational Efficiency in Distributed Operations
A. L. Geoffroy

2

1-3

## ACRONYM & ICON LIST

| | | | |
|---|---|---|---|
| ATDRS | Advanced Tracking and Data Relay Satellite | POIC | Payload Operations Integration Center |
| CDOS | Customer Data and Operations System | POCC | Payload Operations Control Center |
| DOC | Discipline Operations Center | SNC | Space Network Control |
| EMOC | Eos Mission Operations Center | SSF | Space Station Freedom |
| Eos | Earth Observing System | SSCC | Space Station Control Center |
| HST | Hubble Space Telescope | STOCC | Space Telescope Operations Control Center |
| ICC | Instrument Control Center | STS | Space Transportation System (Shuttle) |
| MSOCC | Mission Support Operations Control Center | STSMCC | Space Transportation System Mission Control Center |
| NASCOM | NASA Communications | WSC | White Sands Cpmplex |

ATDRS SSF HST STS Generic Satellite

Space Network Control Workshop,
Goddard Space Flight Center
Dec. 12&13, 1990

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A. L. Geoffroy

2.1
Ref Only

1-4

## DEMANDS ON THE SNC

LARGE NUMBER OF USERS

DIVERSE USER REQUIREMENTS

DIFFERENCES IN TIMING OF INPUT REQUIREMENTS

CONTINGENCY HANDLING

SYSTEM RESPONSIVENESS

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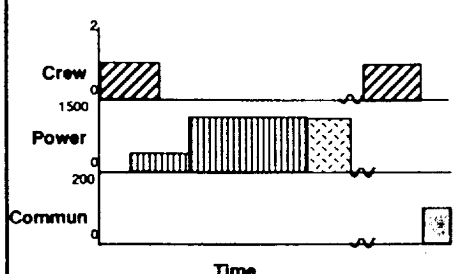
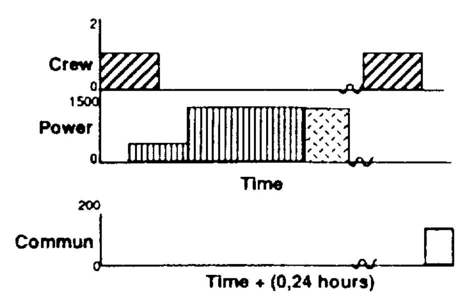
I-5

## TIGHTNESS OF RESOURCE COUPLING




Communications requirements tightly coupled with other resource requirements




Communications requirements loosely coupled with other resource requirements

- TIGHTNESS OF RESOURCE COUPLING
- FIXED v. GENERIC REQUESTS
- CONJUNCTIVE v. INDIVIDUAL REQUIREMENTS
- REAL-TIME REQUIREMENTS

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I-6

## SHARING INFORMATION and SHARING CONTROL

*ACCESS* IN ANY DISTRIBUTED NETWORK MUST BE DISTRIBUTED, BUT *CONTROL* MAY OR MAY NOT BE

WHEN MANY NODES HAVE A LARGE NUMBER OF INTERACTIONS, CENTRALIZED CONTROL EASES THE SCHEDULING PROBLEM

IN NETWORKS WHERE INTER-NODE INTERACTIONS ARE WELL PARTITIONED INTO SMALLER LOCAL NETWORKS, DISTRIBUTED CONTROL IS PREFERABLE

DISTRIBUTION OF CONTROL MAY BE REQUIRED EVEN WHEN THERE IS A HIGH LEVEL OF INTER-NODE INTERACTION, BECAUSE OF :

- SECURITY/PRIVACY
- DISTRIBUTION OF AUTHORITY

FLEXIBILITY OR EFFICIENCY MAY BE LOST IN A NETWORK WITH DISTRIBUTED CONTROL



## POTENTIAL WAYS OF DISTRIBUTING CONTROL

CENTRALIZED CONTROL WITH DISTRIBUTED ACCESS:

- GLOBALLY AVAILABLE INFORMATION
- DECISION MAKING BY CENTRAL AUTHORITY WITH ALL RELEVANT INFORMATION
- RELATIVE PRIORITIES GLOBALLY ESTABLISHED

DISTRIBUTED CONTROL OPTIONS:

- BLOCK RESOURCE ALLOCATION
- CROSS-SCHEDULER NEGOTIATIONS
- CONTROL RE-DIRECTION

## EFFICIENCY PROBLEMS UNRELATED TO DISTRIBUTION OF CONTROL

PROBLEM SIZE

- TOO LARGE FOR ANY KNOWN METHOD OF INTELLIGENT CENTRALIZED SCHEDULING
- TOO MANY INTERDEPENDENCIES FOR EFFICIENCY TO BE MAINTAINED WITH DECOMPOSITION

LEVEL OF PLANNING PROBLEM

- MOVING FROM STRATEGIC PLANNING TO EXECUTABLE SCHEDULES
  - CHANGES IN LEVEL OF DETAIL NECESSITATE EITHER INITIAL OVERBOOKING OR INNEFFICIENT MARGINS
  - CONCURRENCY OF REQUIREMENTS MUST BE TRUE FOR VALID SCHEDULES, BUT ONLY SUMMED REQUIREMENTS ARE AVAILABLE IN EARLY PHASES OF PLANNING

FLEXIBILITY

- THE MORE FLEXIBILITY ALLOWED IN RESOURCE ENVELOPES, THE MORE INEFFICIENCY INTRODUCED



## EFFICIENCY PROBLEMS RELATED TO DISTRIBUTION OF CONTROL

BLOCK ALLOCATIONS

- PREDICTABILITY OF REQUIREMENTS DETERMINES EFFICIENCY

INTERLOCKING SCHEDULES

- TRYING TO ACHIEVE EFFICIENCY IN MULTIPLE DIMENSIONS

SPECIFIC v. GENERIC REQUESTS

- GENERIC REQUESTS CAN BE MOST EFFICIENTLY SCHEDULED, BUT POSE DIFFICULTY IN DISTRIBUTED CONTROL OF TIGHTLY COUPLE RESOURCES

CONTINGENCIES IN DISTRIBUTED CONTROL SCENARIOS

- EFFECTS AT A SINGLE NODE RIPPLE THROUGHOUT NETWORK
- SPEED, RESPONSIVENESS AND COORDINATION PROBLEMS

## RECOMMENDATIONS

STUDY, STUDY, STUDY ....

- RESOURCE COUPLING, INDEPENDENCE
- REAL-TIME REQUIREMENTS
- "COORDINATION" CAPABILITIES
  - DESIRABILITY
  - FEASIBILITY
  - COST RISK & TIMING

DEVELOP APPROACH BASED ON STUDY OUTCOMES, INCLUDING:

- SYSTEM ARCHITECTURE AND DESIGN
- OPERATIONAL REQUIREMENTS/RESTRICTIONS FOR USERS EXPLICITLY GIVEN

N92-11047

# Resource ALlocation Planning Helper

# (RALPH)

David G. Werntz
Jet Propulsion Lab
Pasadena, California

J-1

## RALPH Background

- Developed to plan Deep Space Network tracking, maintenance, and ground based science
  - 12 antennas around the world
  - 30 active users of the DSN
  - Weekly plans
  - Approximately 300 "tracks" per week
- Used to generate schedules up to 2 years in advance
- Developed within Design Team approach (close interaction)
- Operational Since 1987
- Under configuration management since 1989

## RALPH Schedule Lifecycle

| | |
|---|---|
| 10 years - 2 years | Forecasts of resource utilization<br>Forecasts of user contention<br>Evaluation of mission sets |
| 2 years - 8 weeks | Generation of detailed schedules<br>Review and conflict resolution<br>Adaptation to changing requirements |
| 8 weeks - real time | Implementation of schedules<br>Reaction to spacecraft emergencies<br>Reaction to resource outages |

J-3

DGW-2

## Scheduling Approach

- Two pass scheduling
  - Probablistic look-ahead (profile of resource usage)
  - Schedule using profile as measure of expected conflict

- Generic representation of problem
  - Actual problem described by external files (not code)
  - Three types of resources
    - Static
    - Variable
    - Depletable
  - Requirements described in terms of
    - Variable Separations
    - Variable Durations
    - Configuration dependent pre and post activity times
    - User Windows
    - Triggers (Viewperiods)



J-4

DGW-3

## Technology Layering

Applications Level
- DSN (RALPH)
- Space Station Assembly Sequence (FAST)
- Space Station Operations Scheduling Simulation (TOMAS)
- TDRSS Scheduling Prototype

Toolkit Level
- Scheduling
- Resource Look-ahead Profiling
- Interval Algebra
- Conversion routines

Foundation Level - Tree Manipulation Base Routines (TMBR)
- Written in C (fielded on both extended-PC and VAX)
- String storage management
- Dynamic tree manipulation (prune, graft, qualify, etc.)

J-5 DGW-4

## Details

- Approximately 30,000 lines of C code (including TMBR)
- 5 - 30 minutes to generate one week schedule (MicroVAX II)
- Full Environment
  - Form-based requirements entry
  - Graphics (GKS) and text-based (Curses) schedule editors
  - Listings
  - Plots
  - Import and export facilities
  - Multi-user system

# RALPH Directions

- Migrate towards more iterative rescheduling capability
- C++ version in the works
- Change operational platform to network environment
- Expand representational base
- Continue to expand base of applications

J-7

DGW-6

30-MAY-1989 13:38

RESOURCE ALLOCATION PLAN
ACTIVITIES LISTING FOR TDRSS
WEEK NUMBER 43 OF YEAR 1988

PAGE: 1

| ID | DAY | START END HRS-MIN | FACLTY | USER | ACTIVITY | PRE | BOT EOT HRS-MIN | PST | CO-USER(S) FLAG | CONF FLAG |
|---|---|---|---|---|---|---|---|---|---|---|
| Monday October 24 | | | | | | | | | | |
| 001 | 298 | 0000-0010 | KSW | STS | CONTINUOUS SSA | 005 | 0005-0010 | 000 | | |
| 002 | 298 | 0000-0015 | MARW | HST | CONTINUOUS MAR | 005 | 0005-0015 | 000 | | |
| 003 | 298 | 0000-0035 | MARE | HST | CONTINUOUS MAR | 005 | 0005-0035 | 000 | | |
| 004 | 298 | 0000-0040 | KSE | STS | CONTINUOUS SSA | 005 | 0005-0040 | 000 | | |
| 005 | 298 | 0010-0035 | KSW | LST4 | 7_SSAF_PER_DAY | 005 | 0015-0035 | 000 | | |
| 006 | 298 | 0020-0035 | MAFE | HST | 1_MAF_PER_ORB | 005 | 0025-0035 | 000 | | |
| 007 | 298 | 0035-0105 | MAFE | ERBS | 1_MAF_EV_OTH_ORB | 005 | 0040-0105 | 000 | | |
| 008 | 298 | 0035-0100 | MAFW | SME | 1_MAF_PER_ORB | 005 | 0040-0100 | 000 | | |
| 009 | 298 | 0040-0105 | KSE | LST5 | 7_SSAF_PER_DAY | 005 | 0045-0105 | 000 | | |
| 010 | 298 | 0045-0145 | KSW | STS | CONTINUOUS SSA | 005 | 0050-0145 | 000 | | |
| 011 | 298 | 0100-0115 | MAFW | LST5 | 7_MAF_PER_DAY | 005 | 0105-0115 | 000 | | |
| 012 | 298 | 0100-0155 | MARW | HST | CONTINUOUS MAR | 005 | 0105-0155 | 000 | 014<br>017 | |
| 013 | 298 | 0120-0220 | KSE | STS | CONTINUOUS SSA | 005 | 0125-0220 | 000 | | |
| 014 | 298 | 0130-0200 | MARW | ERBS | 1_MAR_EV_OTH_ORB | 005 | 0135-0200 | 000 | 012<br>017 | |
| 015 | 298 | 0135-0215 | MARE | HST | CONTINUOUS MAR | 005 | 0140-0215 | 000 | | |
| 016 | 298 | 0135-0150 | MAFE | LST4 | 7_MAF_PER_DAY | 005 | 0140-0150 | 000 | | |
| 017 | 298 | 0150-0240 | MARW | SME | 1_MAR_PER_ORB | 005 | 0155-0240 | 000 | 012<br>014 | |
| 018 | 298 | 0200-0225 | KSW | LST4 | 7_SSAR_PER_DAY | 005 | 0205-0225 | 000 | | |
| 019 | 298 | 0215-0245 | MAFE | ERBS | 1_MAF_EV_OTH_ORB | 005 | 0220-0245 | 000 | | |
| 020 | 298 | 0220-0245 | KSE | LST5 | 7_SSAR_PER_DAY | 005 | 0225-0245 | 000 | | |

N92-11048

JPL

# USER INTERFACE ISSUES IN SUPPORTING HUMAN - COMPUTER INTEGRATED SCHEDULING

Presented to:
Space Network Control Conference on
Resource Allocation Concepts and Approaches

December 12 -13, 1990

Lynne P. Cooper
Eric W. Biefeld

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California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109
Mail Stop 301-490

Previously presented at the Fourth Annual Space Operations, Applications, and Research Symposium
Albuquerque, New Mexico June 1990

Operations Mission Planner

K-1

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# OUTLINE

- Introduction
- Background
- Issues
- OMP Interface
- Acknowledgements

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K-2

SOAR/GFSC 2

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# CHARACTERISTICS OF AN OMP SCHEDULE DOMAIN

**Resource Allocation Problem**

- Over-Subscribed
- Large Numbers of Complex Requests
- Changes in Tasking
- Changes in Environment

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K-3

SOAR/GFSC-3

JPL

# WHAT IS A SCHEDULE?

**Request**

Task

Activity

Set of Steps

Frame

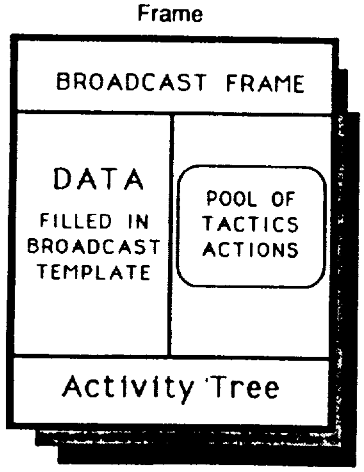
**Antenna**

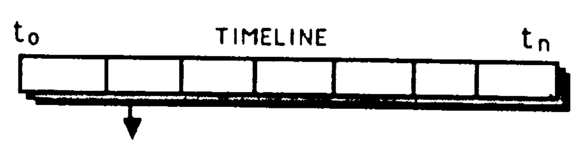
Resource

Timeline

Chronology

Temporal Data Base of Steps, Usage, & Direction




Broadcast 508

Broadcast 632

Direction 53

Chronogram C-12

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K-4

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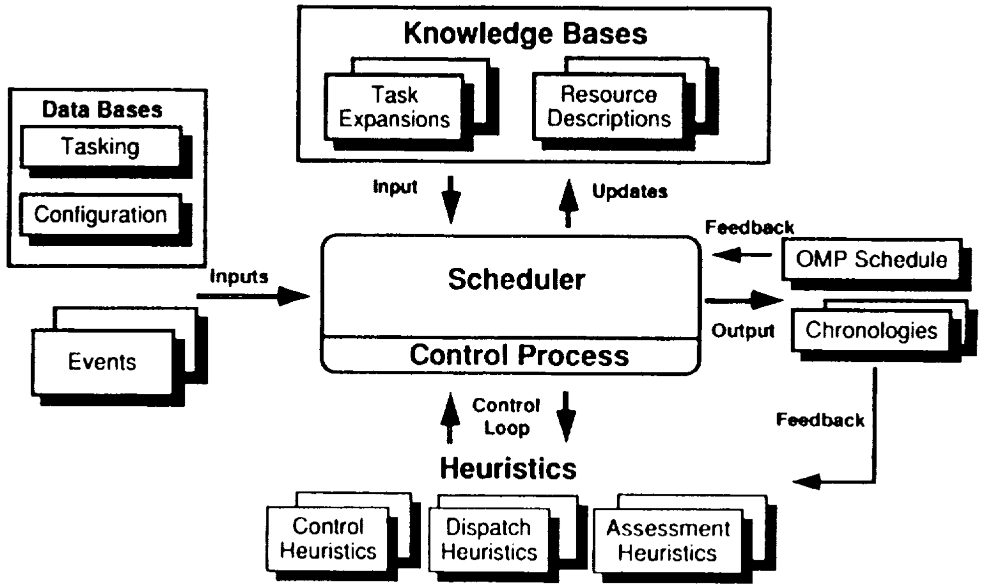
# OMP ARCHITECTURE

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# Picture of OMP Interface

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K-6

SOAR/GESC 6

# ISSUES

## OMP Interface Designed as Developmental Interface for Automated Scheduling System

| | |
|---|---|
| • Information Underload → | Strip Charts |
| • Information Overload → | Histograms, Filtered Gantt |
| • Modifying Tasks → | Edit Window |
| • Events → | Command Window |
| • Assessment of Schedule → | Statistics Display |
| • Development/Modification of Heuristics → | Animated Windows<br>Chronologies<br>Parameter Setting |

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K-7

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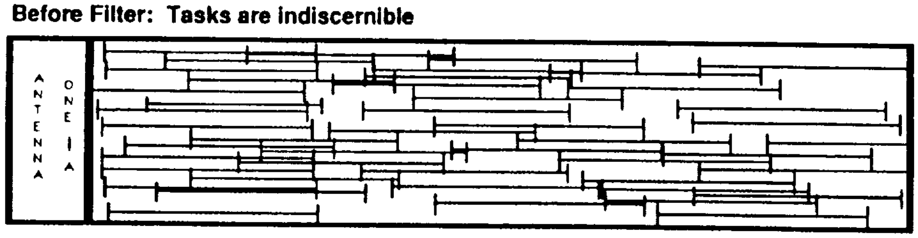
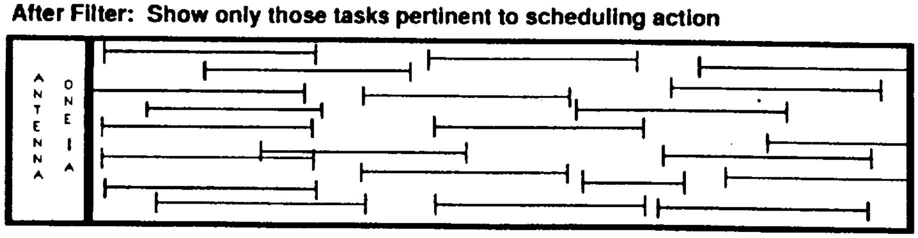
# Example: Information Overload

When deleting tasks, show only the lower priority tasks which form the deletion pool

**Before Filter: Tasks are indiscernible**




**After Filter: Show only those tasks pertinent to scheduling action**

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# USER INTERFACE DIMENSIONS

Two major considerations in specifying a user interface:

- Functional Distribution
- Type of User

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# Functional Distribution

## Example: Operations Mission Planner

| Automated Functions | Human Functions |
|---|---|
| Develop Schedule | ID New Heuristics |
| Assess Schedule | Direct Manipulation of Schedule |
| Modify Schedule | Provide Guidance |
| | "Verify" Schedule |
| | Monitor Schedule Execution |
| | ID Problems During Scheduling |
| **Process** | **Monitor Create** |

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# Types of Users

**Different Types of Users Require Different Support from the Interface**

### Human Scheduler

- Adjust Scheduling Process
- Interpret Results of Scheduling Algorithms
- Modify Heuristics
- Perform Statistical Analysis
- Define New Heuristics

### Schedule End-User

- Focus Scheduler
- Define Performance Limits
- Request Sequential Activities Lists
- Set Preferences

### Both

- Manipulate Tasks
- Manipulate Resources
- Input New Tasking
- Receive Output Schedules

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# INTERPRETING USER INTERACTION

Need to interpret user interaction in the development of a schedule somewhere in the middle of the continuum

User Modification to Schedule is ABSOLUTE

Scheduler Can IGNORE Any User Change to Schedule

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K-12

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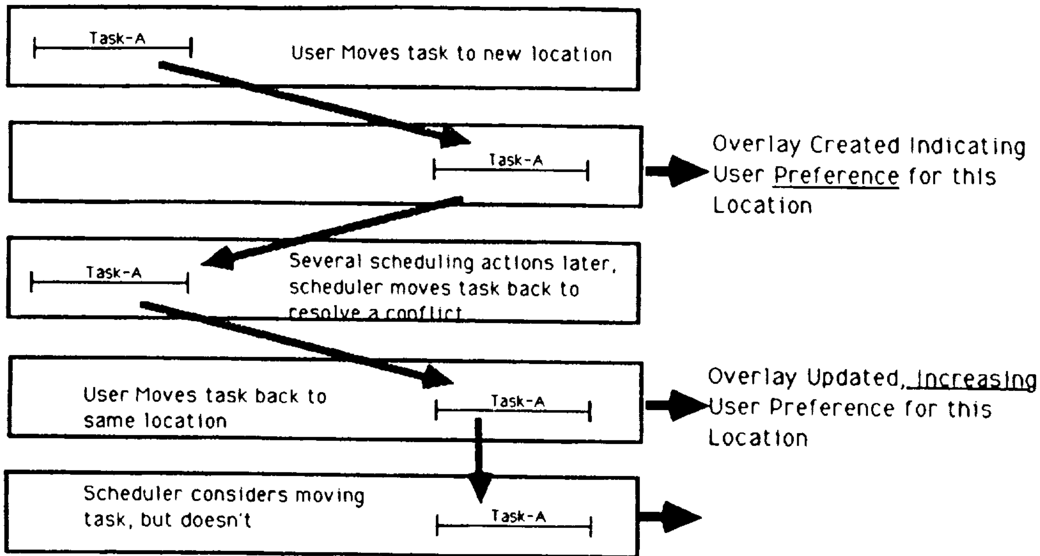
## Example:
## Interpreting User Interaction Using
# DYNAMIC OVERLAYS

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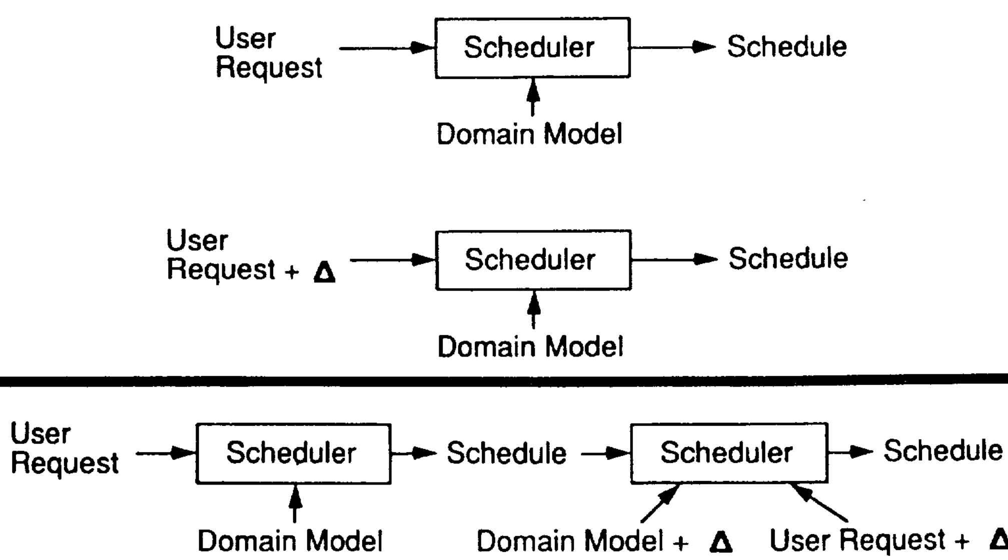
# REACTIVE SCHEDULING

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AIWG 12/90-15

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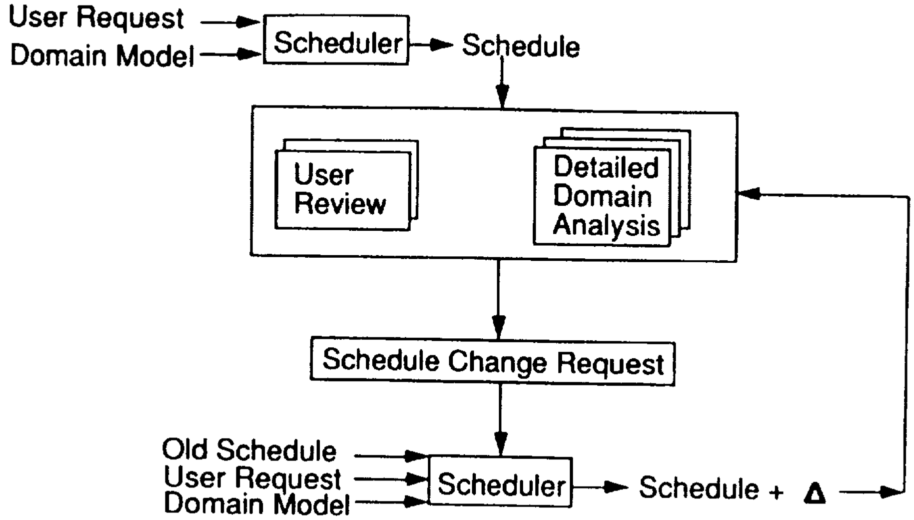
# REACTIVE SCHEDULING CONT

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AIIWG 12/90-18

**JPL**

# TRANSITIONING THE INTERFACE

**OMP is in the process of identifying how to transition from an automated/developmental interface to an integrated/operational interface**

| | Automated | H-C Integrated |
|---|---|---|
| Developmental | OMP<br>Provide user insight into what scheduling actions are being performed and why the scheduler is choosing those actions (DEBUGGING) | Develop heuristics which can be interactive with the user. Provide feedback to the user on how his actions are affecting the schedule (INTERACTIVE DEBUGGING) |
| Operational | Assist an end-user of the SCHEDULE in the process of input/output for the scheduler (BLACK BOX OPERATIONS) | Assist a human scheduler in providing guidance to the scheduler (INTERACTIVE SCHEDULING) |

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K-16

SOAR/GFSC-14

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# ACKNOWLEDGEMENTS


OMP Research has been sponsored by CIA/ORD, NASA Code R, NASA Code M, and the JPL Flight Projects Support Office

- Technical Lead - Research, Design, & Development

  *Eric Biefeld*

- Design & Development Support

  *Lynne Cooper*

- Other Team Members

  *David Atkinson, Leonard Charest, Richard Doyle, Loretta Falcone, Jim Firby, Kirk Kandt, Ray Lam, Gaius Martin, Elmain Martinez,Harry Porta*


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K-17

SOAR/GFSC 15

N92-11049

# HUMAN FACTORS ISSUES IN THE DESIGN OF USER INTERFACES FOR PLANNING AND SCHEDULING

**PRESENTED AT THE SPACE NETWORK CONTROL CONFERENCE ON RESOURCE ALLOCATION CONCEPTS AND APPROACHES**

**NASA/GODDARD SPACE FLIGHT CENTER**

**DECEMBER 13, 1990**

**Presented by:**

**Elizabeth D. Murphy**

**CTA INCORPORATED**
**6116 Executive Boulevard, Suite 800**
**Rockville, MD 20852**
**(301) 816-1262**

L-1

## PREFACE

THE SYSTEM MUST BE BASED UPON A SIMPLE, CONCEPTUALLY USEFUL MODEL OF THE SCHEDULING PROCESS, THE USER INTERFACE MUST BE NATURAL AND INTUITIVE, AND THE COMMANDS MUST PROVIDE A DIRECT MAPPING OF THE INTENTION INTO ACTION.

--FOX, 1989

. . . THE FIRST STEP FOR THE DESIGNER IS TO DETERMINE THE FUNCTIONALITY OF THE SYSTEM BY ASSESSING THE USER TASK DOMAIN.

--SHNEIDERMAN, 1987





L-2

# AGENDA

- INTRODUCTION
- ISSUES
- GUIDELINES
- DISPLAY CONCEPTS
- GENERAL RECOMMENDATIONS

L-3

HF-2

# INTRODUCTION

- PURPOSE — PROVIDE AN OVERVIEW OF HUMAN FACTORS ISSUES THAT IMPACT THE EFFECTIVENESS OF USER INTERFACES TO AUTOMATED SCHEDULING TOOLS
- SCOPE — SELECTED ISSUES ADDRESSED IN RECENT WORK FOR NASA-GODDARD CODE 522.1



L-4

## INTRODUCTION (2)

- METHOD
  - SURVEY OF PLANNING AND SCHEDULING TOOLS
  - IDENTIFICATION AND ANALYSIS OF HUMAN FACTORS ISSUES
  - DEVELOPMENT OF DESIGN GUIDELINES BASED ON HUMAN FACTORS LITERATURE
  - GENERATION OF DISPLAY CONCEPTS TO ILLUSTRATE GUIDELINES

L-5

HF-4

## ISSUE: VISUAL REPRESENTATION OF THE SCHEDULE

- OBJECTIVE: REDUCE MENTAL MANIPULATION AND TRANSFORMATION OF DATA
- OPERATIONAL NEED:
  - ALTERNATIVE LEVELS OF ABSTRACTION
  - SUPPORT FOR VISUALIZING RELATIONSHIPS BETWEEN EVENTS
  - SUPPORT FOR REORDERING EVENTS
  - REDUCED DEMAND ON MEMORY

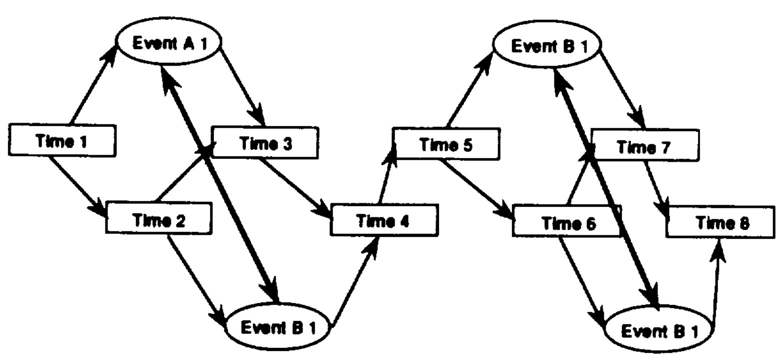
## ISSUE: VISUAL REPRESENTATION OF THE SCHEDULE (2)

- GUIDELINE: CONSIDER ALLOWING A SPECIFIC TEMPORAL ORDERING OF EVENTS TO EVOLVE OVER THE SCHEDULE'S LIFE CYCLE.
- DISPLAY CONCEPT: PRECEDENCE SCHEDULING
  - FOCUS ON RELATIONSHIPS BETWEEN EVENTS AND POINTS IN TIME
  - USE EVENT "CLONES" TO REPRESENT ALTERNATIVE SATISFACTION OF CONSTRAINTS ON AN EVENT

L-7

HF-6

## DISPLAY CONCEPT: PRECEDENCE SCHEDULING






L-8

## ISSUE: EVALUATION OF SCHEDULES

- OBJECTIVE: INCREASE THE EASE AND EFFECTIVENESS OF SCHEDULE COMPARISON AND SELECTION
- INFORMATION REQUIREMENTS/CRITERIA:
  - NUMBER OF REQUESTS SATISFIED
  - LEVEL OF RESOURCE FRAGMENTATION
  - AVERAGE PERCENTAGE OF SERVICE PROVIDED
  - PERCENTAGE OF SERVICE PER USER

L-9

HF-8

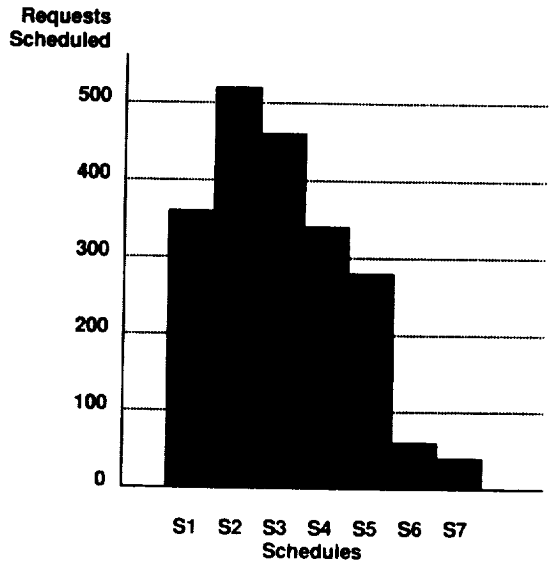
## ISSUE: EVALUATION OF SCHEDULES (2)

- GUIDELINE: PROVIDE A CAPABILITY THAT SUPPORTS QUICK VISUAL COMPARISON OF SCHEDULES
- DISPLAY CONCEPT: HISTOGRAM
  - CONVEYS RELATIVE EFFECTIVENESS OF ALTERNATIVES
  - REDUCES MENTAL COMPARISON OF DISCRETE QUANTITIES



L-10

## DISPLAY CONCEPT: HISTOGRAM




HF-10

L-11

## ISSUE: IDENTIFICATION OF AVAILABLE RESOURCES

- OBJECTIVE: SUPPORT OPERATOR HEURISTICS FOR MAXIMIZING USE OF RESOURCES (E.G., NEGOTIATION WITH USER, RESOURCE SUBSTITUTION)
- OPERATIONAL NEED/INFORMATION REQUIREMENTS:
  - DISCRETE RESOURCE AVAILABILITIES (AMOUNT BY TIME)
  - REQUESTED RESOURCES
  - FUNCTIONALITY FOR COMPARISON OF REQUESTED AND AVAILABLE RESOURCES

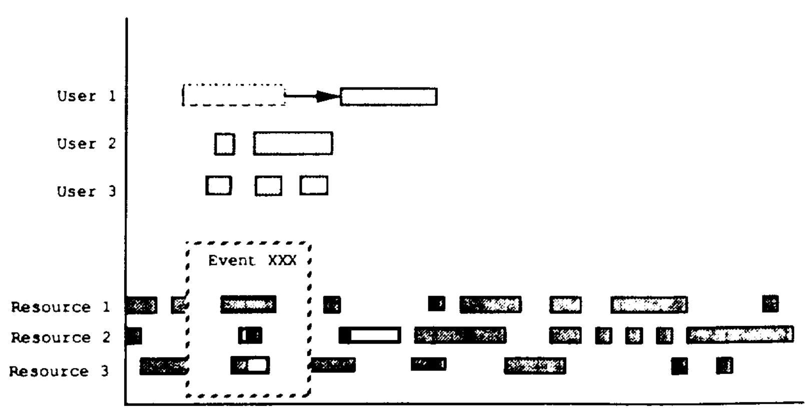
## ISSUE: IDENTIFICATION OF AVAILABLE RESOURCES (2)

- GUIDELINE: PROVIDE ACCESS TO RESOURCE AVAILABILITIES; SUPPORT COMPARISON OF AVAILABLE AND REQUESTED RESOURCES; SUPPORT RESOURCE SUBSTITUTION.
- DISPLAY CONCEPT: GRAPHICAL REPRESENTATION OF AVAILABLE RESOURCES
  - FEATURES DIRECT-MANIPULATION APPROACH TO COMPARISON OF REQUESTED AND AVAILABLE RESOURCES

L-13

HF-12

## DISPLAY CONCEPT: GRAPHICAL REPRESENTATION OF AVAILABLE RESOURCES






L-14

## ISSUE: SUPPORT FOR CONFLICT RESOLUTION

- OBJECTIVE: PROVIDE SUPPORT FOR OPERATOR'S MENTAL PROCESS OF CONFLICT RESOLUTION
- OPERATIONAL NEEDS/INFORMATION REQUIREMENTS
  - RESOURCE AVAILABILITIES
  - REQUEST CONTENTS AND FLEXIBILITIES
  - CHANGES IN PRIORITIES
  - USERS AND EVENTS IN CONFLICT
  - EXTENT OF EXISTING CONFLICTS
  - RESOURCE USAGE PER USER
  - REQUEST-EDIT CAPABILITY

L-15

HF-14

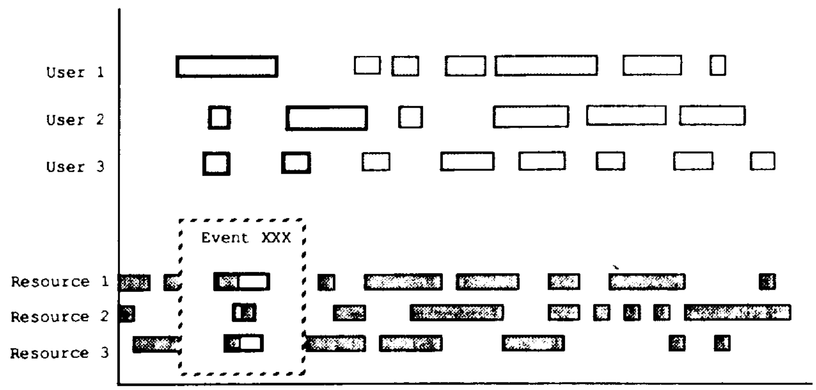
## ISSUE: SUPPORT FOR CONFLICT RESOLUTION (2)

- GUIDELINE: PROVIDE SUPPORT FOR CONFLICT RESOLUTION BASED ON ANALYSIS OF OPERATOR'S GOALS AND MENTAL OPERATIONS; INVOLVE OPERATORS FULLY IN THE DEVELOPMENT PROCESS
- DISPLAY CONCEPTS: DISPLAY OF CONFLICTING EVENTS
  - OPTION 1: HIGHLIGHTING CONFLICTS
  - OPTION 2: SUPPRESSING NON-CONFLICTING EVENTS



L-16

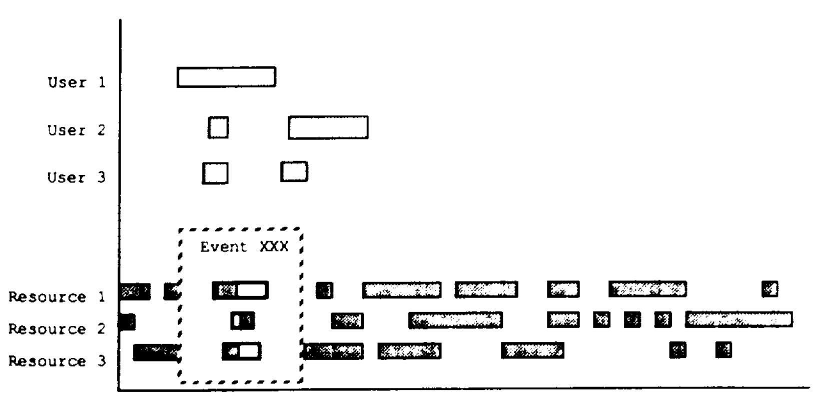
## DISPLAY CONCEPT: DISPLAY OF CONFLICTING EVENTS (OPTION 1 - HIGHLIGHTING CONFLICTS)




HF 16

L-17

## DISPLAY CONCEPT: DISPLAY OF CONFLICTING EVENTS (OPTION 2 - SUPPRESSING NON-CONFLICTING EVENTS)






L-18

## GENERAL RECOMMENDATIONS

- BASE DISPLAY DESIGN ON OPERATIONAL TASK ANALYSIS (FOCUS ON COGNITIVE TASK ANALYSIS
- SUPPORT VISUALIZATION, DIRECT MANIPULATION OF DATA
- KEEP OPERATORS IN THE DEVELOPMENT LOOP

L-19

HF-18

## REFERENCES

FOX, B.R. (1989). MIXED INITIATIVE SCHEDULING. PAPER PRESENTED AT THE AAAI-STANFORD SPRING SYMPOSIUM ON AI IN SCHEDULING, STANFORD, CA.

SHNEIDERMAN, B. (1987). DESIGNING THE USER INTERFACE. READING, MA: ADDISON-WESLEY.

WEILAND, W. J., BAHDER, S. A., & MURPHY, E. D. (1990). DESIGN OF PLANNING AND SCHEDULING INTERFACES: GUIDELINES AND DISPLAY CONCEPTS (DSTL-90-027). GREENBELT, MD: NASA/GODDARD SPACE FLIGHT CENTER.

COPIES OF THE GUIDELINES DOCUMENT (WEILAND, BAHDER, & MURPHY, 1990) MAY BE OBTAINED BY WRITING TO:

SYLVIA SHEPPARD
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GREENBELT, MD 20771

N92-11050

# FLEXIBLE ENVELOPE REQUEST NOTATION ( FERN )

December 13, 1990

David Zoch
David LaVallee
Stuart Weinstein

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## Agenda

- Background
- FERN Language Concepts
- FERN Syntax Examples

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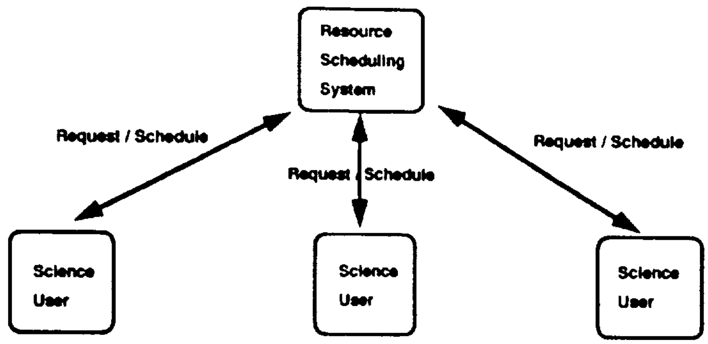
## Scheduling Application




- Science users send requests to the Resource Scheduling System.
- Requests are requirements for planned instrument operations and are written in FERN.
- The Resource Scheduling System, which may reside in a POCC, processes the requests and generates a schedule.
- The schedule specifies the timeline of user activities and is distributed to the science users.

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## Motivation for FERN

- Science users must represent their resource requirements and constraint relationships in a format that can be interpreted by computers.
- If their initial resource requests cannot be satisfied, science users need to propose reduced resource amounts or alternative experiments for their instrument operations. Thus, some of the science user requests may be flexible and complex rather than simple.
- FERN uses a language format. For example, "TAPE_DUMP for 5 minutes to 10 minutes" is more user-friendly than "TAPE_DUMP,5,10." This format allows users to state their requirements in a more direct and natural manner.

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## Characteristics of FERN

- ROBUST
  - Supports a variety of user resource requirements and constraints.
  - Supports alternative resource amounts and requests.
  - Supports repetitive requests ("generic requests") based on orbital events rather than specific start times.
- READABLE
  - Keyword based, not positional. For example, avoids "ROB1,2-4,60,200-300."
- FLEXIBLE
  - Time durations and relaxable constraints
- OBJECT-ORIENTED
  - Data abstraction
  - Reusable data objects

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## Types of Information Needed in Requests

- ***Flexible*** resource requirements
- ***Flexible*** request durations
- ***Flexible*** experiment timing / coordination requirements between activities
- Scheduling information for repetitive activities
- ***Alternative*** activities
- Relative importance of each requirement

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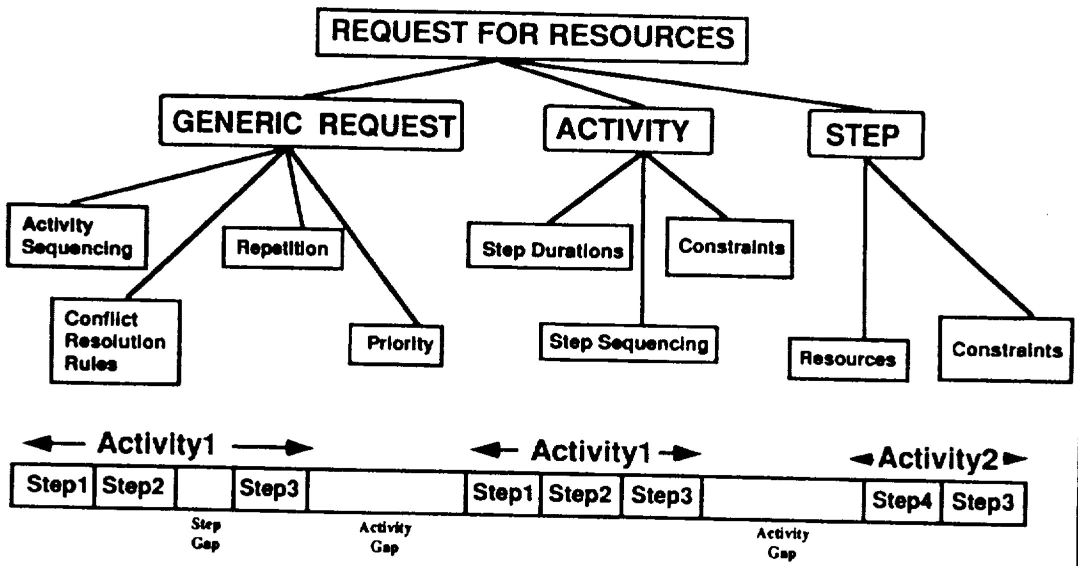
## Where Information is stored in Requests

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## FERN Structures

GENERIC REQUEST
- Pattern of replication of activities
- Alternative activities
- Rules

ACTIVITY
- Sequence of steps that comprise the activity
- Duration of steps
- Constraints common to whole activity
- Defined in database, then referenced by name in GENERIC REQUEST

STEP
- Amounts of resources
- Constraints
- Defined in database, then referenced by name in ACTIVITIES

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## FERN Structures (cont'd)

**RESOURCES**

- Support user operations.
- Are represented as scalars that vary over time.

**CONSTRAINTS**

- Restrict the times when a request can be scheduled.
- Are specified with respect to timegraphs, activities, steps, or other requests.

**TIMEGRAPHS**

- Are used to specify time windows, view periods, preferable scheduling times, spacecraft events, calendar events, etc.

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## Generic Request

**Generic** *GENERIC_NAME* **is**
**3 to AS MANY AS POSSIBLE activities per** *Sun_in_view*
**With default min start time separation** 5 minutes,
**With default max start time separation** 10 minutes,
**With summed duration** 4 hours, -- sum of multiple activity durations is 4 hours
**With priority** 2,
**With strategy** Maximizing_Separation
**Schedule**
*ACTIVITY1* **and** *ACTIVITY2*
**Or schedule**
*ACTIVITY3*
**Or schedule**
*ACTIVITY4* **With min start time separation** 4 minutes
**End generic**

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## Activity

**Activity** *ACTIVITY_NAME* **is**
**Steps**
*STEP1* **for** 1 **to** 8 minutes,
**idle** *STEP2* **for** 2 **to** 5 minutes,
*STEP3* **for** 5 minutes,
**interruptable** *STEP4* **for AS LONG AS POSSIBLE**,
*STEP5* **for** 5 minutes
**With activity duration** 30 minutes
**End activity**

**Interruptable Step -** resources of step can be re-allocated without disrupting activity.

**Idle Step -** same as interruptable, but not displayed on timeline. Used to represent idle periods.


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## Step

**Step** *STEP_NAME* **is**
**Resources**
*INSTRUMENT_X,*
*POWER 5 watts,*
*TDRSS_SA 1,*
...
**Constraints**
**Occurs entirely during** *ORBIT_DAYLIGHT,*
**Starts at the same time as** *ACTIVITY_X,*
...
**End step**

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# Resources

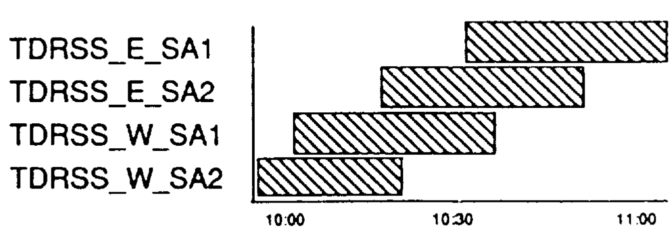
- Initial amount may vary over time in discrete steps
- Pooled resources contain equivalent or nearly equivalent items:
  - TDRSS is (TDRSS_E, TDRSS_W)
  - Crew member is (commander, pilot, mission_specialist)
  - Redundant equipment is (line_recorder_1, line_recorder_2)
- Some resources are available at different times to different users (e.g., TDRS)
- Resources may be either durable or consumable



# Pooled Resources

**Resource** *TDRSS_SA* **is**
**(Forever** (*TDRSS_E_SA1, TDRSS_E_SA2,*
*TDRSS_W_SA1, TDRSS_W_SA2*))
**End resource**

TDRSS_SA Allocation




Even though some TDRSS_SA is available at every point, no single antenna is continuously available. Thus, a request for 50 minutes of TDRSS_SA is NOT satisfied.

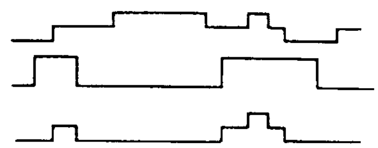
## Resource Availability for Pooled Resources

**Some resources are available at different times to different users**

***For example, TDRSS communication resources are available at different times to different satellites, depending on the position of the satellite with respect to TDRSS.***

**Step** *DATA_LINK* **is**
**Resources**
*TDRSS_E*
**Constraints**
**Occurs entirely during** *TDRSS_IN_VIEW*
**End step**

TDRSS_E
TDRSS_IN_VIEW
Availability



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## Expressive Notation

**Supports non-specific durations:**

*VIEW_STAR_STEP* **for AS LONG AS POSSIBLE**
*RECALIB_STEP* **for** 2 **to** 8 minutes

**Supports flexible requests where the resource amounts and duration of the request are selected by alternative relaxation levels. This capability allows the scheduling algorithm to reduce resource amounts or shorten the duration of the request in order to fit the request on the schedule:**

*RESOURCE1* 15 units,
*RESOURCE2* (25 units, 23 units **AT RELAXATION** 4,
19 units **AT RELAXATION** 8,
15 units **AT RELAXATION** 12)

*STEP1* for (30 minutes, 28 to 30 minutes **AT RELAXATION** 5,
25 to 30 minutes **AT RELAXATION** 15)

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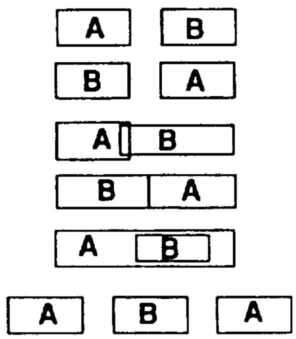
## Temporal Constraints

- Temporal Constraints specify when a request can be scheduled with respect to:

  *Calendar Events, Orbital Events, Requests, or User Defined Events*
- Allow for precise activity sequencing and coordinated activity dependencies.
- Sample temporal relationships between request A and object B are:




Occurs before B

Occurs after B

Ends 5 minutes after the start of B

Occurs right after B

Overlaps all of B

Does not overlap B

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## Profiles

Things that vary over time

FOREVER

CREATE

CREATE PERIODIC

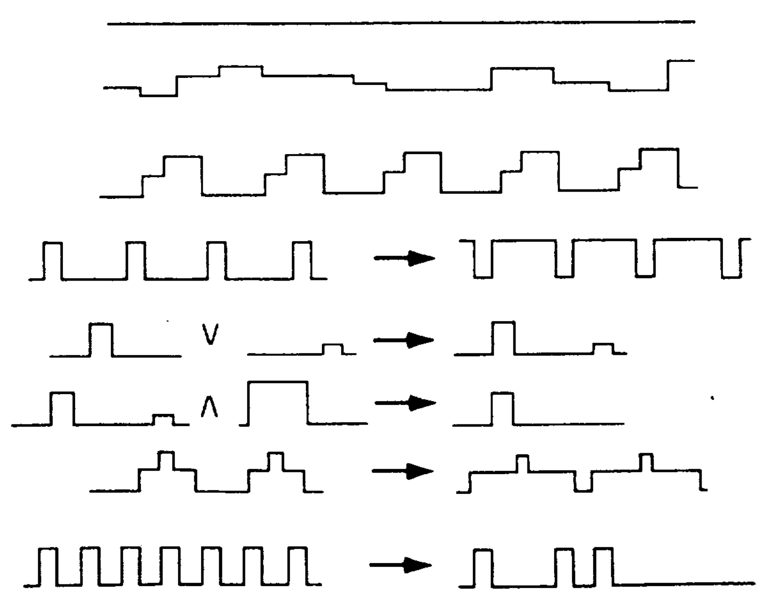
INVERT

UNION

INTERSECT

MODIFY
With start earlier by 5,
With end later by 5

SELECT 1,3,4

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## Time Formats

**Representation of Absolute Time:**

| | |
|---|---|
| • 1990/120/09:00:15.12 | April 30, 1990, 9:00:15.12 am |
| • 1990/120-09:00:15.12 | April 30, 1990, 9:00:15.12 am |
| • 1990/4/30-09:00:15.12 | April 30, 1990, 9:00:15.12 am |

**Representation of Relative Time:**

| | |
|---|---|
| • 3/2:30 | 3 days, 2 hours, and 30 minutes |
| • 2.5 | 2 hours, 30 minutes |
| • 2.5 hours | 2 hours, 30 minutes |
| • :24.25 | 24 minutes, 15 seconds |
| • 24.25 minutes | 24 minutes, 15 seconds |

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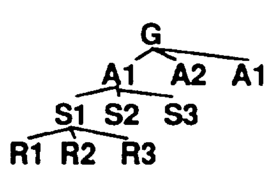
## Changes to FERN

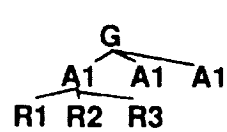
**New FERN**

- UIL like - keywords
- Generic repetition by iteration or user-defined windows
- Direct support of alternatives
- Flexible duration
- Pooled resources
- Database of steps




**Old FERN**

- LISP like - ( )
- Generic repetition by iteration
- Alternatives by mutual exclusion
- Fixed duration only
- No pooled resources
- Unnamed phases

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## Sample FERN Requests

**Support the following features:**

-- Temporal relationships between steps or activities

-- Maximum activity length to limit step delays

-- Alternative requests

-- Idle resource usage between steps of the same activity

-- Flexible request durations

-- Relaxable constraints

-- Event driven planning/scheduling concepts

-- ESP and UIL time formats

-- Step oriented (generics -> activities -> steps)

-- Min and max delays between steps and activities

-- User priorities

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## Temporal Relationship between Two Steps

**Problem:** The steps ERBS_TR_DUMP and ERBS_RANGING occur concurrently when command uplink and telemetry downlink are available (coherent transponder mode). This example shows how to specify relationships between steps by using a constraint expression.

**Step** *ERBS_TR_DUMP* **is**
**Resources**
*TDRSS_I_CHANNEL_FORWARD_LINK,* -- *mode 1.0 kbps*
*TDRSS_I_CHANNEL_RETURN_LINK ,* -- *mode 1.6 kbps*
*TDRSS_Q_CHANNEL_RETURN_LINK* -- *mode 32 kbps*
**End step**

**Step** *ERBS_RANGING* **is**
**Resource**
*TWO_WAY_RANGING_AND_DOPPLER 1,*
**Constraint**
**Occurs entirely during** *ERBS_TR_DUMP*
**End step**

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## Maximum Activity Length to Limit Step Delays

**Problem:** The transition between steps is flexible and does not need to occur at a specific time. Switching from command uplink only mode to command uplink and telemetry downlink mode may begin from 5 to 7.5 minutes after the ERBS activity start time.

**Activity** *ERBS_NORMAL_CASE* **is**
**Steps**
*ERBS_CMD_LOAD_AND_DOPPLER* **for** 5 minutes **to** 7.5 minutes,
*ERBS_CMD_LOAD* **for** 2.5 minutes **to** 5 minutes,
*ERBS_TR_DUMP_AND_RANGING* **for** 13 minutes,
*ERBS_TR_DUMP* **for** 10 minutes
**With activity duration for** 33 minutes
**Constraint**
**Starts during** *ERBS_WINDOW*
**End activity**



## Alternative Requests

**Problem:** In some cases, all of the activities (instances) belonging to a generic request cannot be scheduled. Alternative requests are backup requests which tell the scheduling system how to resolve conflicts. In this example, the last alternative request applies only to those activities (instances) that remain unscheduled after the nominal request and first alternative request were processed.

**Generic** *ERBS_SUPPORT* **is**
**1 activity per** *EVERY_TWO_ERBS_ORBITS*
**Schedule** -- schedule nominal first
*ERBS_NORMAL_CASE*
**Or schedule** -- move ranging step to try to resolve resource conflict
*ERBS_RETURN* **and** *ERBS_SMALL_WINDOW_TRACKING*
**Or schedule** -- if one of the ERBS activities cannot be scheduled, place it within the next 3 orbits
*ERBS_BIG_WINDOW_RETURN* **and** *ERBS_BIG_WINDOW_TRACKING*
**End generic**

## Temporal Relationship between Two Activities

**Problem:** The CLAES instrument normally views for three days on and three days off. However, during a spacecraft yaw manuever, the science user wants to interrupt the normal view activity to close the instrument's aperature door. The normal view activity resumes after the spacecraft yaw manuever.

**Activity** *CLAES_CLOSED_DOOR_VIEW_ACT* **is**
**Steps**
*CLAES_CLOSE_APERATURE_STEP* **for** 1 minute,
*CLAES_DOOR_CLOSED_VIEW_STEP* **for as long as possible,**
*CLAES_OPEN_APERATURE_STEP* **for** 1 minute,
**Constraints**
**Overlaps exactly** *UARS_YAW_MANUEVER*
**Occurs entirely during** *CLAES_NORMAL_VIEW_ACT*
**End activity**

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## Idle Resource Usage between Steps

**Problem:** The HALOE instrument alternately views the sunrise and sunset. In between, it is stowed. The idle step is used to maintain the minimum resources required for stowing between viewing.

**Activity** *HALOE_NORMAL_ACT* **is**
**Steps**
*HALOE_SUNRISE_VIEW_STEP* **for** 15 minutes,
*HALOE_SUNRISE_SLEW_TO_STOW_STEP* **for** 20 seconds,
**idle** *HALOE_STOW_STEP* **for** as long as possible, -- limited to about 25 minutes
*HALOE_SUNSET_VIEW_STEP* **for** 15 minutes,
*HALOE_SUNSET_SLEW_TO_STOW_STEP* **for** 15 seconds,
**idle** *HALOE_STOW_STEP* **for** as long as possible -- for remainder of orbit
**End activity**

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# CHIMES-2: A Tool for Automated HCI Analysis

Space Network Control Conference on
Resource Allocation Concepts and Approaches

December 13, 1990

Presented By
William J. Weiland

CTA INCORPORATED
6116 Executive Boulevard, Suite 800
Rockville, MD 20852
(301) 816-1332

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## OVERVIEW OF PRESENTATION

- COMPUTER-HUMAN INTERACTION MODELS (CHIMES) METHODOLOGY
- CHIMES-2 PROTOTYPE
- CHIMES FUTURE DEVELOPMENT



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## PURPOSES OF CHIMES METHODOLOGY AND TOOLSET

- FOR FIELDED COMPUTER-HUMAN INTERFACES
  - EVALUATE DEMANDS
  - PINPOINT TROUBLE SPOTS

- FOR PLANNED CHI DESIGNS
  - PREDICT IMPACTS OF DESIGN CHANGES
  - SELECT FROM DESIGN ALTERNATIVES

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CHI-2

## CHIMES: A THEORETICAL MODEL OF HUMAN PERFORMANCE

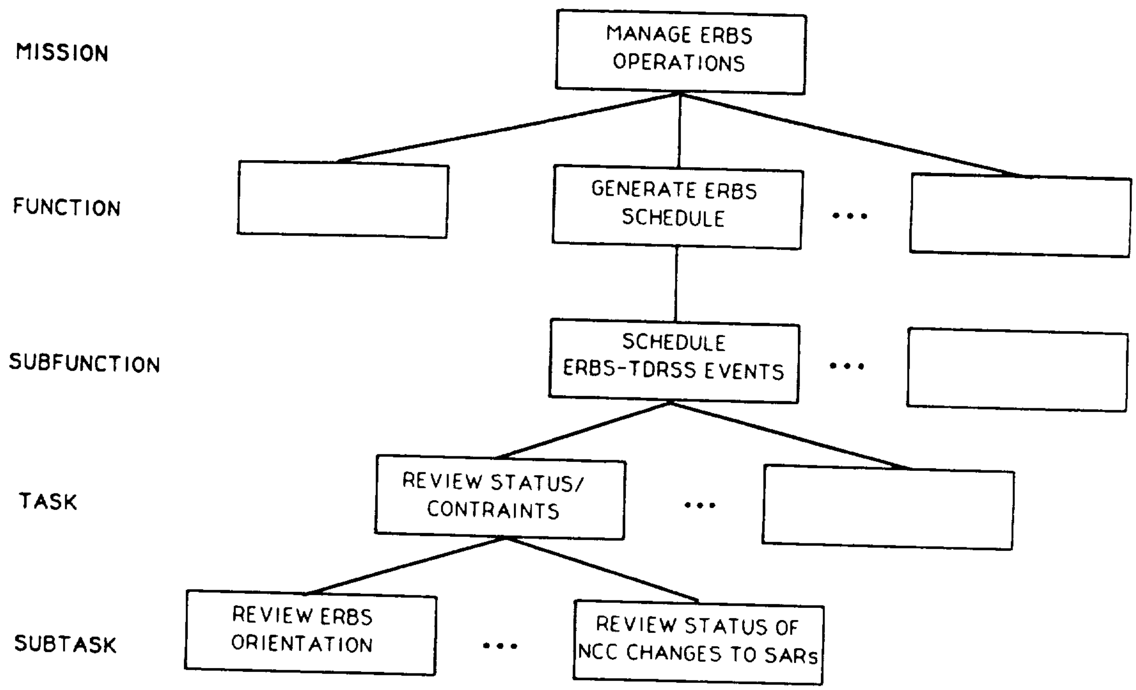
BASIC PREMISES:

- SYSTEMS IMPOSE DEMANDS ON PERSONNEL RESOURCES
  - COGNITIVE
  - SENSORY
  - MOTOR

- OPERATIONAL FUNCTIONS CAN BE MODELED IN TERMS OF A HIERARCHY OF FUNCTIONAL LEVELS AND ATTRIBUTES

- EVALUATION OF DEMANDS ON OPERATORS IS A BASIS FOR IMPROVING HUMAN-COMPUTER INTERACTION

## CHIMES: SAMPLE FUNCTIONAL HIERARCHY

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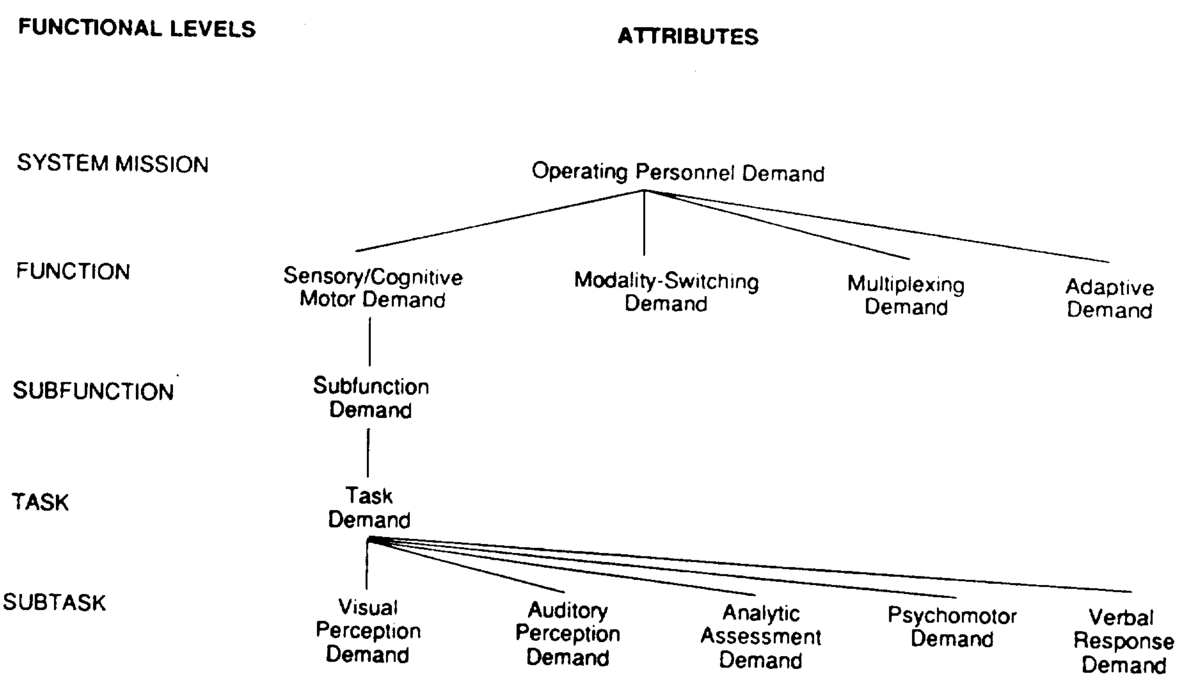
CHI-4

## CHIMES DEMAND MODEL: HIERARCHY OF ATTRIBUTES



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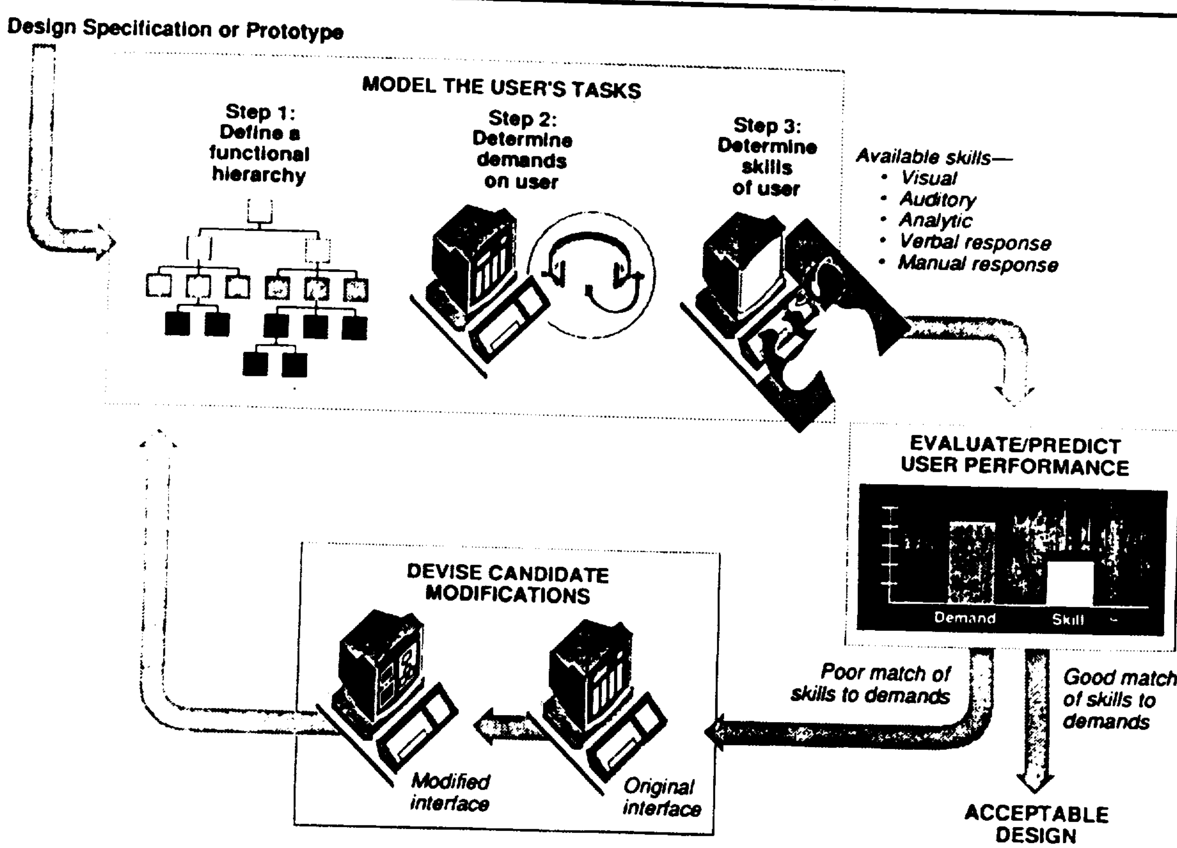
## CHIMES PROCESS

- MODEL THE OPERATOR'S JOB
- RATE DESIGN-BASED DEMANDS ON OPERATOR RESOURCES: VISUAL, AUDITORY, ANALYTIC, VERBAL, AND MANUAL
- EVALUATE OR PREDICT OVERALL OPERATOR WORKLOAD AND PERFORMANCE)
- IDENTIFY ACTUAL OR POTENTIAL TROUBLE SPOTS (HIGHS AND LOWS FOR WORKLOAD, LOWS FOR PERFORMANCE
- DEVELOP RECOMMENDATIONS TO IMPROVE THE QUALITY OF HUMAN-COMPUTER INTERACTIONS

N-7 CHI-6

## OVERVIEW OF CHIMES METHODOLOGY

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## CHIMES-2 PROTOTYPE

- PROVIDE PROOF-OF-CONCEPT FOR CHIMES-2 CAPABILITIES
  - USER-SYSTEM INTERFACE
  - KNOWLEDGE BASES
  - DISPLAY ANALYSIS
  - MODIFICATION ADVICE
  - EXPLANATION FACILITY
- FOCUS ON EVALUATION OF A SINGLE ALPHANUMERIC DISPLAY SCREEN
  - VISUAL DEMAND
  - ANALYTIC DEMAND

CHI-8

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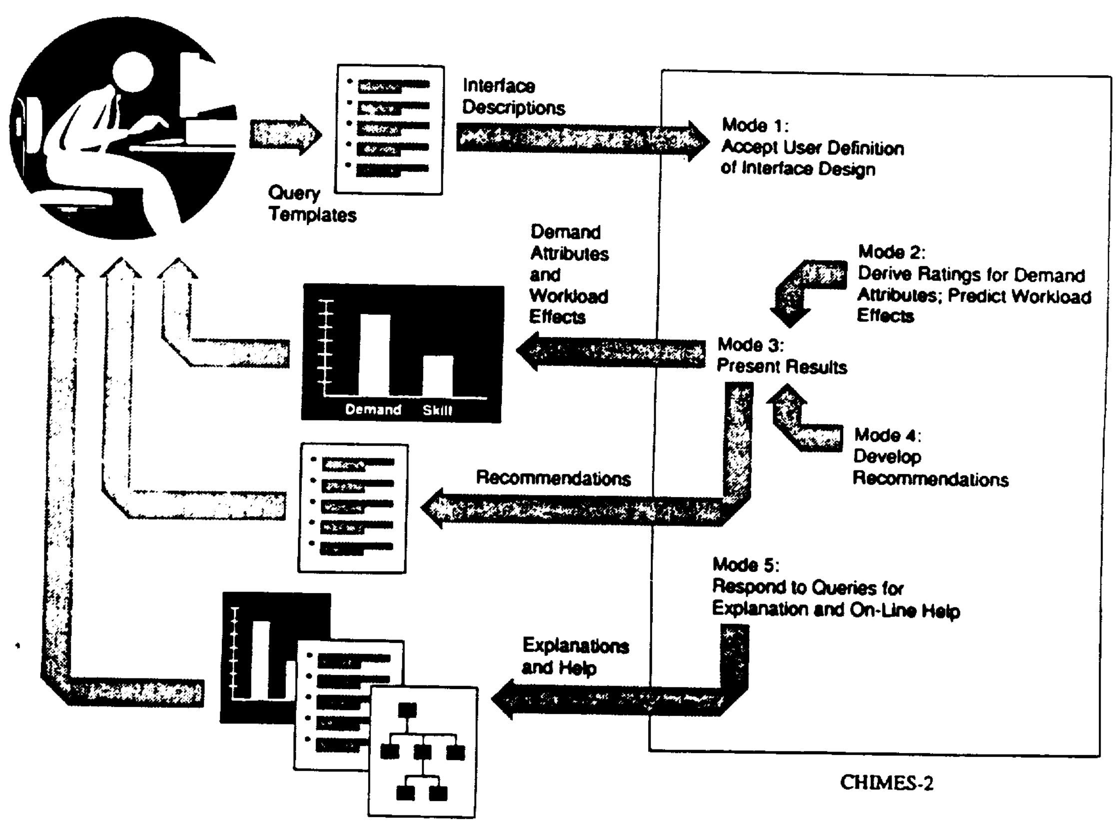
## CHIMES-2 PROTOTYPE: SYSTEM MODES




CHIMES-2

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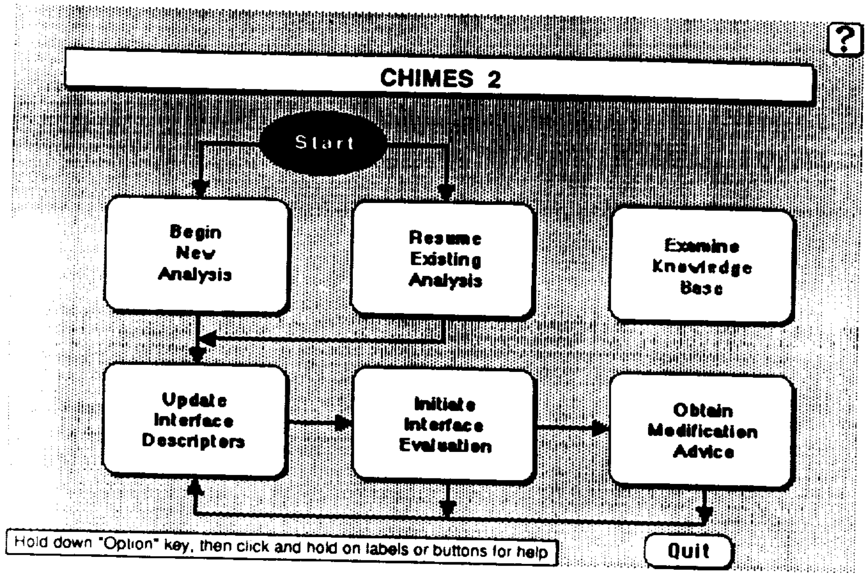
## TOP-LEVEL CHIMES-2 SCREEN

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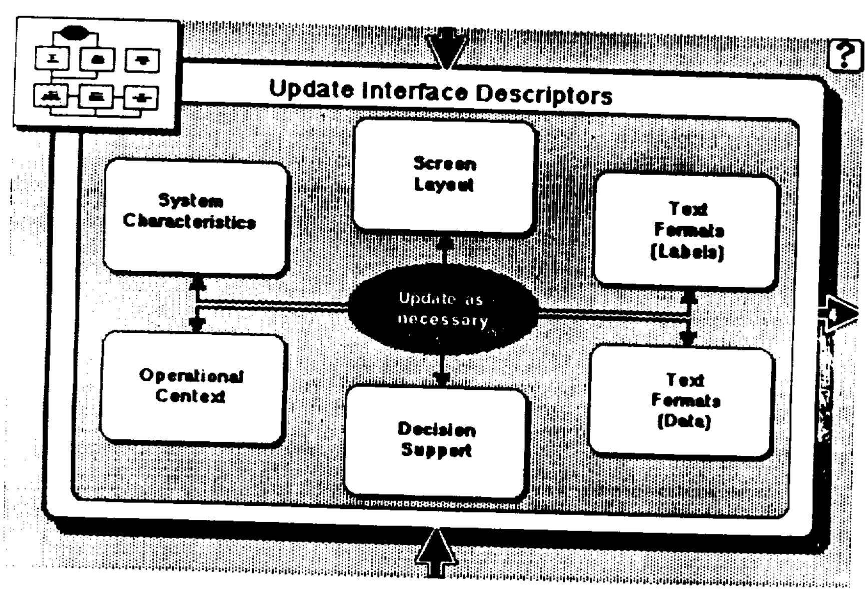
## INTERFACE SPECIFICATION SCREEN



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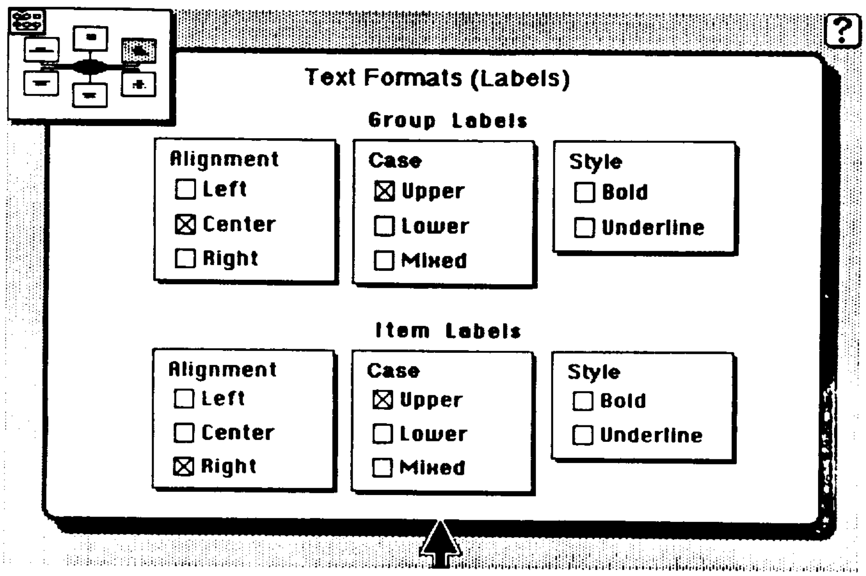
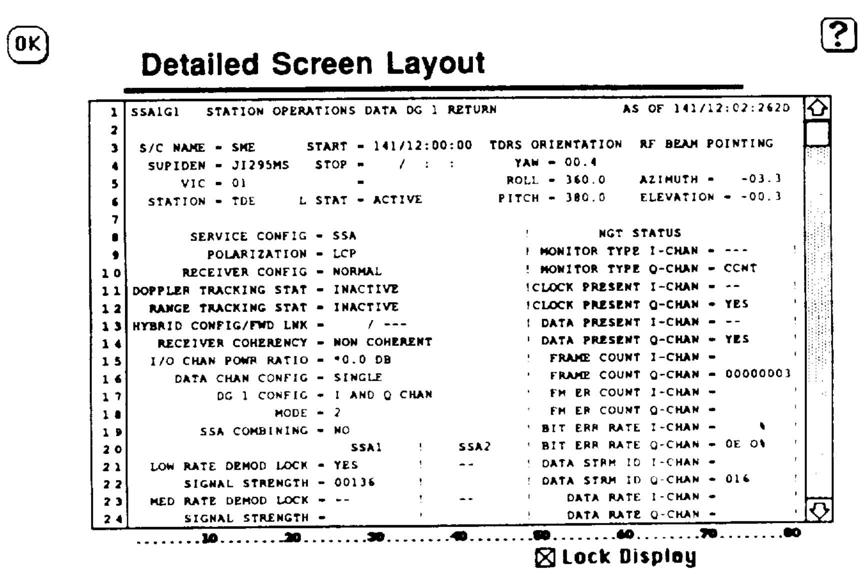
## SAMPLE LOW-LEVEL DESCRIPTION SCREEN






## ALTERNATE LOW-LEVEL DESCRIPTION SCREEN



## CHIMES FUTURE DEVELOPMENT

- GRAPHICS/COLOR ANALYSIS CAPABILITY
- REFINEMENT OF CHIMES MODEL
- INTEGRATION WITH INTERFACE PROTOTYPING TOOL
- INTEGRATION WITH REQUIREMENTS ANALYSIS TOOL

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CHI-14

# TRUST
# TDRSS Resource User Support Tool

**Thomas P. Sparn**
**R. Daniel Gablehouse**

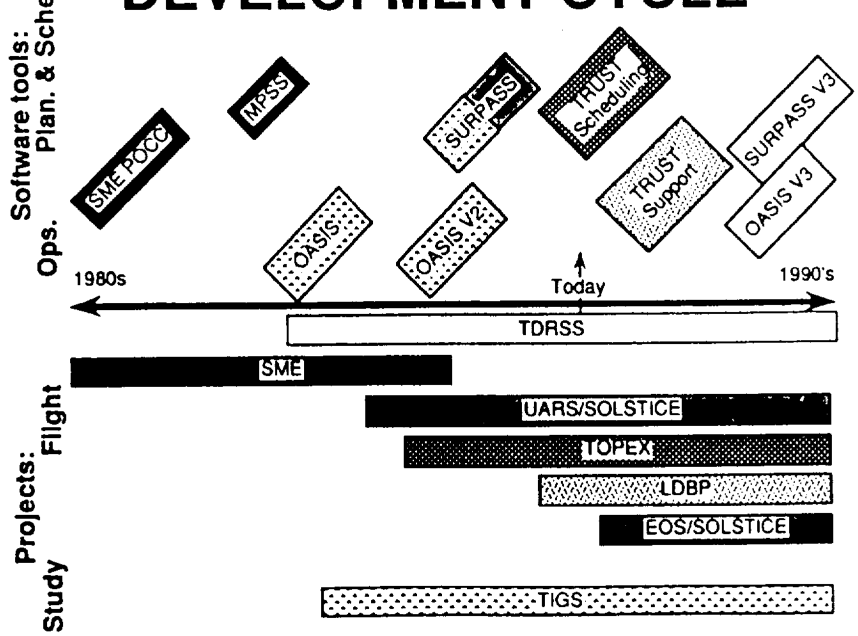
**Laboratory for Atmospheric and Space Physics**

**University of Colorado**





# TRUST
# DEVELOPMENT CYCLE



# TRUST DEVELOPMENT

**Flight Projects**

- Solar Mesosphere Explorer (SME): Realtime Control and Monitoring; Science Planning and Scheduling; TDRSS Scheduling and Ground Control
- Solar/Stellar Irradiance Comparison Experiment (SOLSTICE): Science and Mission Planning; Instrument Monitoring, Command and Control
- Ocean Topography Experiment (TOPEX - JPL): LASP Involvement Includes TDRSS Scheduling
- Long Duration Balloon Project (LDBP - GSFC/WFF): LASP Involvement Includes TDRSS Scheduling and Ground Control

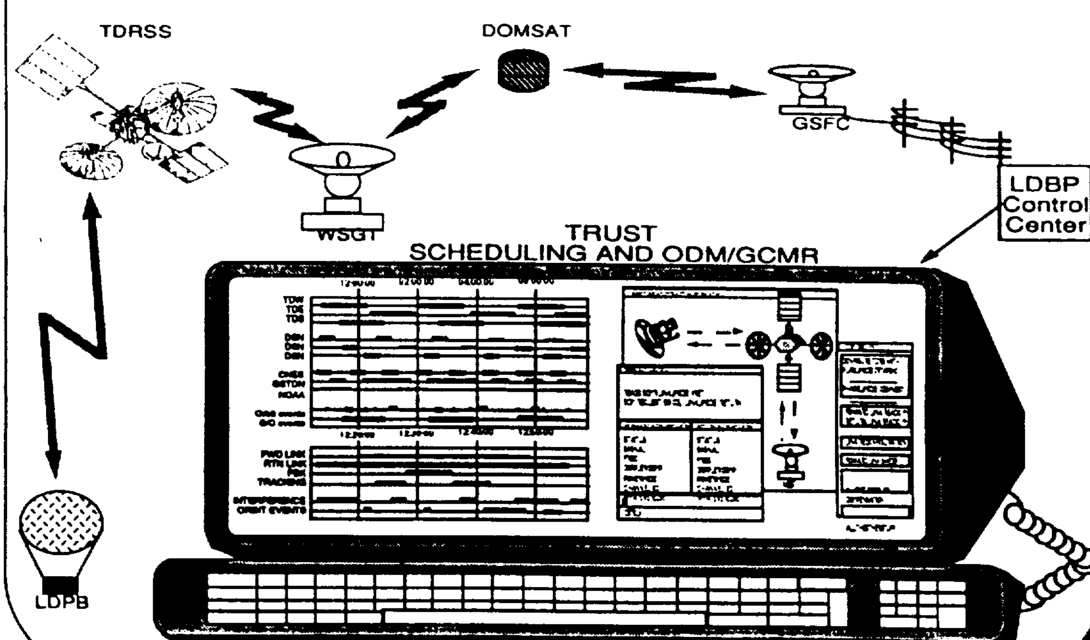
**Study Projects**

- Telescience Implications on Ground Systems, Scheduling Architectures Concepts and Networks (TIGS SCAN Testbed - GSFC): LASP Involvement Includes Planning and Scheduling; Instrument Operations





# The TRUST System



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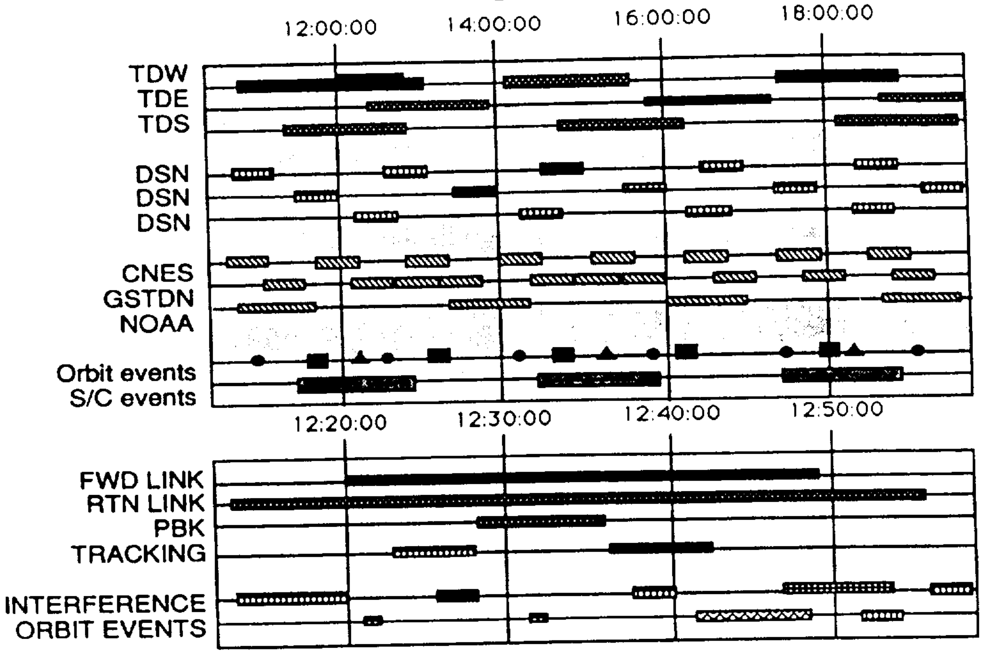
# Scheduling Window

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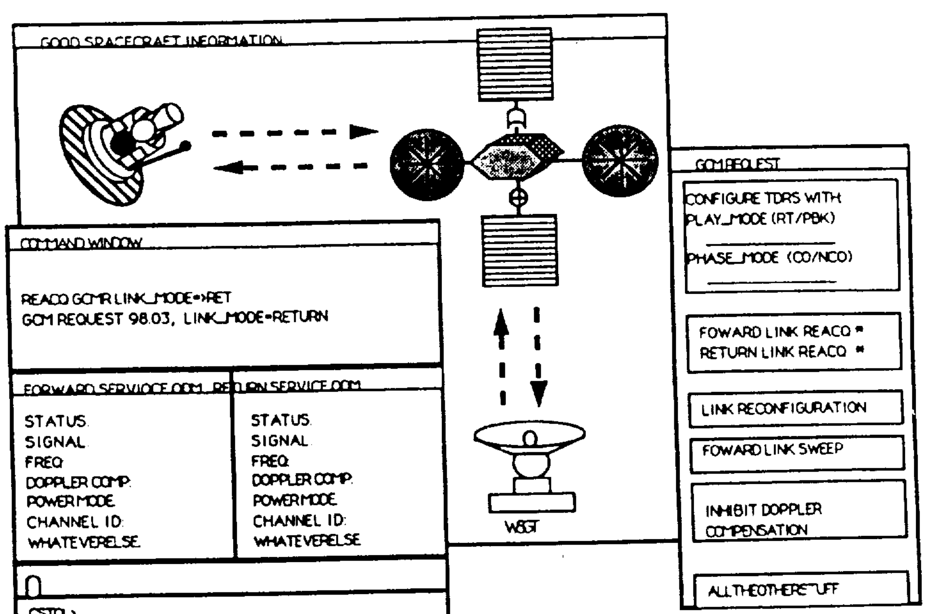
# ODM/GCMR Window

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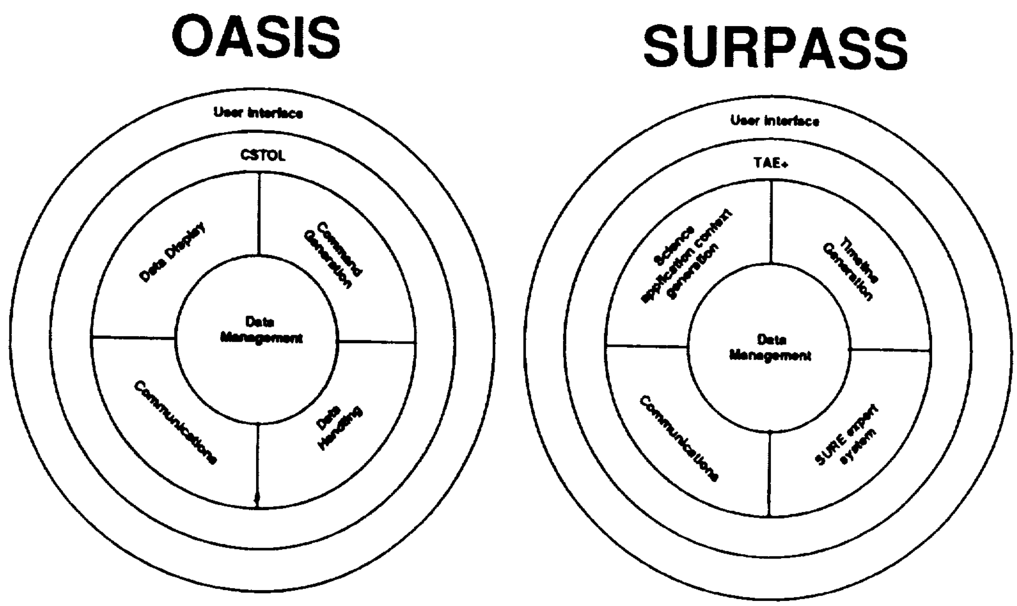
# TRUST Architecture



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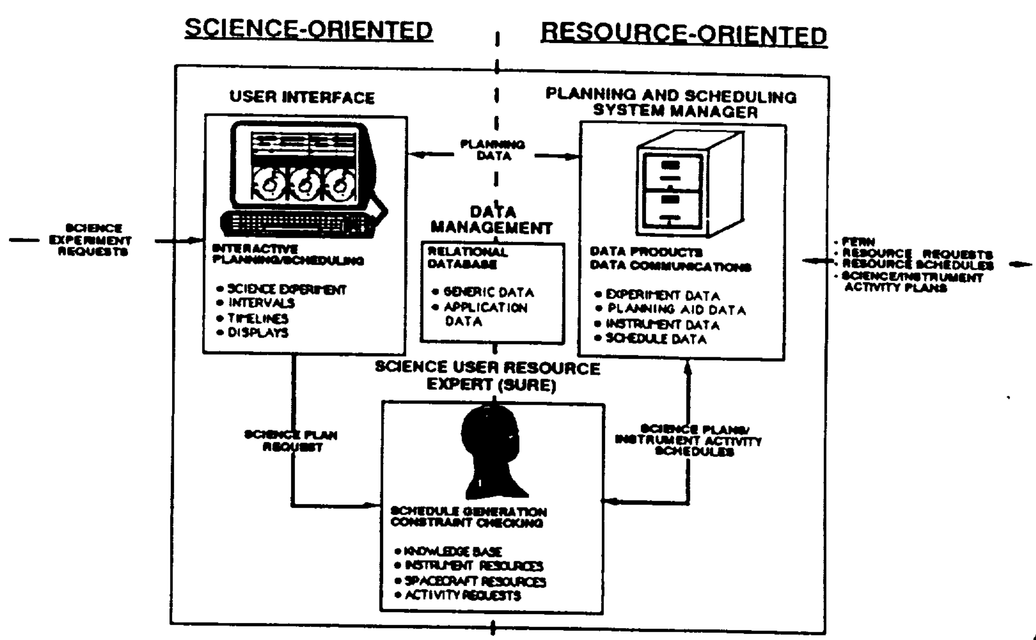
# SURPASS



# SUMMARY

- Generic TDRSS Scheduling with use of the Expert System
- Automatic Re-scheduling, for conflict resolution, with Expert System
- ODM/QDM Processing and Constraint Checking
- Trend analysis of TDRSS link, as an aid to TDRSS Operations
- Capable of formatting schedule messages, to allow scheduling of multiple networks (TDRSS, DSN, etc.)
- Receives and processes Spacecraft PSAT & Orbital Information
- Capable of handling several communications protocols (NASCOM, SPAN/DECNET, TCPIP, etc.)
- Supplies planner/scheduler/operator a view of possible activities, in the Scientific/Mission Context (X Window Based)
- Menu driven GCMR, Schedule Requests & Processing, if desired
- Multi Spacecraft Capability
- Written Entirely in Ada

N92-11053

# Network Control Center User Planning System (NCC UPS)

Brian Dealy
Computer Sciences Corporation

**December 1990**

**Space Network Control Conference on Resource Allocation Concepts and Approaches**

00-1

DSTD
Code 520

## Agenda

- Ups System Overview
- Scheduling Interfaces
- Graphics scheduling Aid

GSFC / CSC





00-2

## UPS Overview

Hardware / software Configuration

Unix Platforms running X11R4 and OSF Motif 1.1.1

Posix compliant with a few exceptions

Uses TAE Plus 4.1 - 5.0, A GUI builder developed by NASA

Software to run on various host CPUs





## NCC UPS Role

Replace each of the current Mission Planning Terminals (MPTs) as the user interface to the NCC.

This interface includes:

- Interactive entry of TDRSS schedule requests
- Processing of batch request from other systems
- Transmission of requests to the NCC
- Receipt of confirmed schedules from the NCC
- Reporting to users

## Major NCC UPS Functional Requirements

Provide input and validation of orbital data

Provide UPS database management

Provide interactive and batch input and validation of schedule requests

Provide transmission of SARs to the NCC

Provide reception of NCC messages and reporting to users





## Interactive User Access Levels

- The Mission Coordinator:
  - Modifies database definitions
  - Adds and deletes users
  - Enters and modifies static data in the Translation
  - Map and User Environment Tables
- The Mission Scheduler:
  - Reads orbital data from tape
  - Generates schedule requests
  - Transmits SARs to the NCC
  - Generates reports and queries
- The Mission User:
  - Generates predefined reports
  - Reviews scheduling information

## UPS Interfaces

- The UPS user:
  - Provides ISRs and other supporting data
  - May be one of two types:
    - -- Interactive
    - -- Electronic
- The NCC:
  - Receives SARs from the UPS
  - Transmits confirmed schedules, rejected requests, and schedule updates to the UPS

8315I(7)





## Interactive User Subsystem

- Supports interactive functions
  - Information window
  - System administration
  - Mission setup
  - Orbital data operations
  - Automatic schedule request generation
  - Specific schedule request generation
  - Mission database maintenance
  - Report generation
  - Database queries
  - Message transmission

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## Interface Navigation

All Subsystems available from pulldown on information window

Attempted to limit interface depth to three levels where possible

Information which has been entered previously should default for lower level screens (e.g. start, stop time)

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00-9

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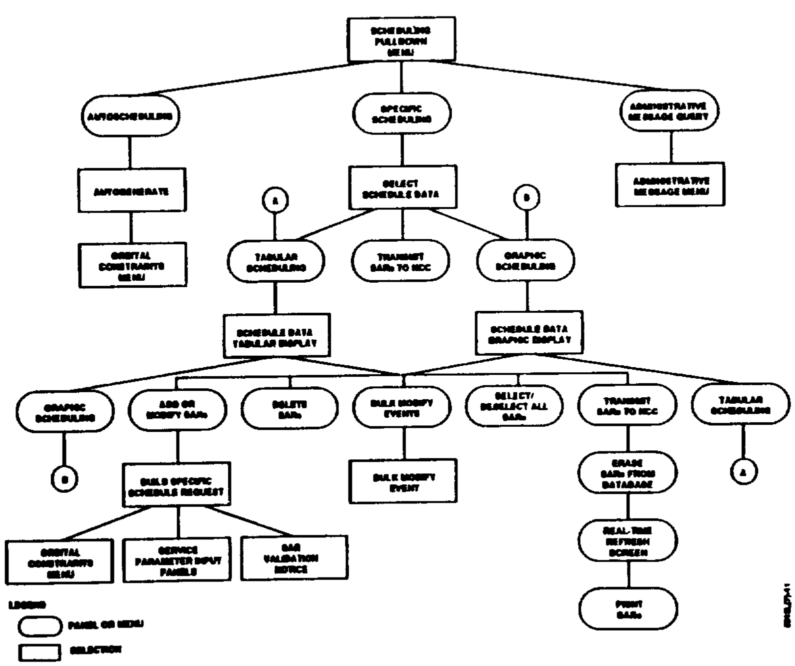
## Scheduling Screen Hierarchy



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00-10

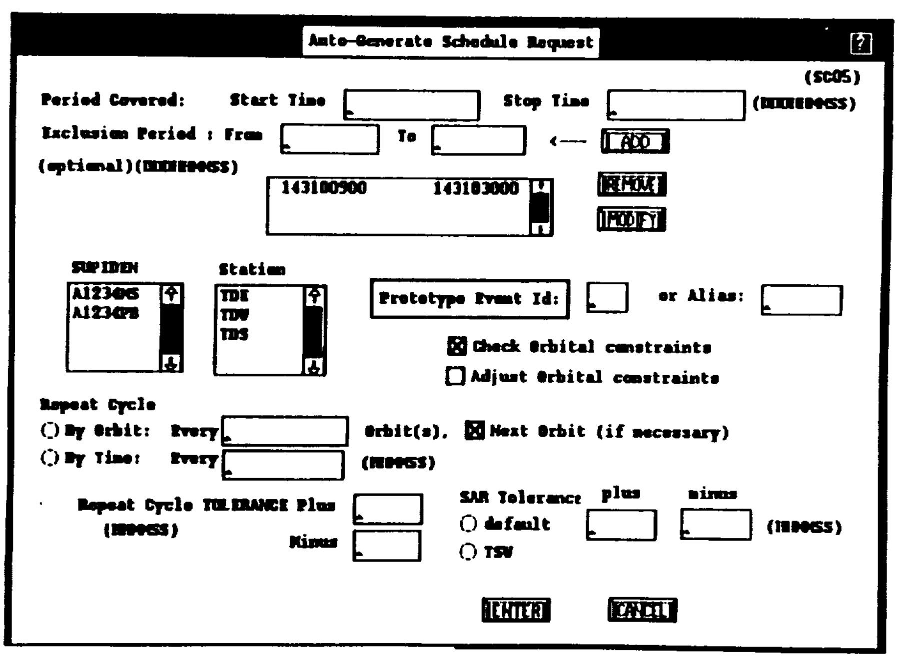
# Interactive Scheduling Input Panels

- Autoscheduling
  - Autogenerate schedule request (autogenerate main panel)
    - -- Orbital constraints menu (for adjusting orbital constraints)
- Specific scheduling
  - Select schedule data (specific main panel)
    - -- Schedule data tabular display (for tabular scheduling)
    - -- Schedule data graphic display (for graphic scheduling)
  - Build specific schedule request (for adding/modifying SARs)
    - -- Orbital constraints menu (for adjusting orbital constraints)
    - -- Service parameter input panels (for editing respecifiable parameters)
    - -- SAR validation notice (for saving to database)
  - Bulk modify event (for bulk modifying SARs)





# Autogenerate Schedule Request Panel



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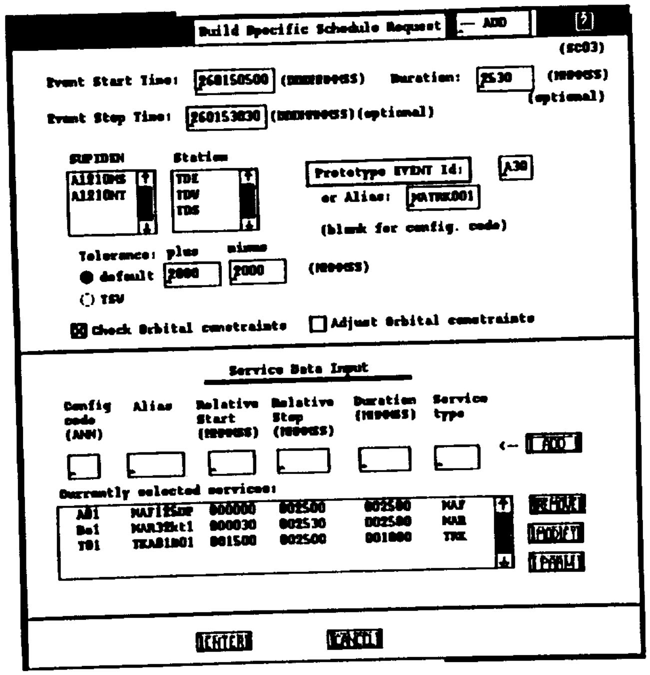
Code 520

## Build Specific Schedule Request Panel

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00-13

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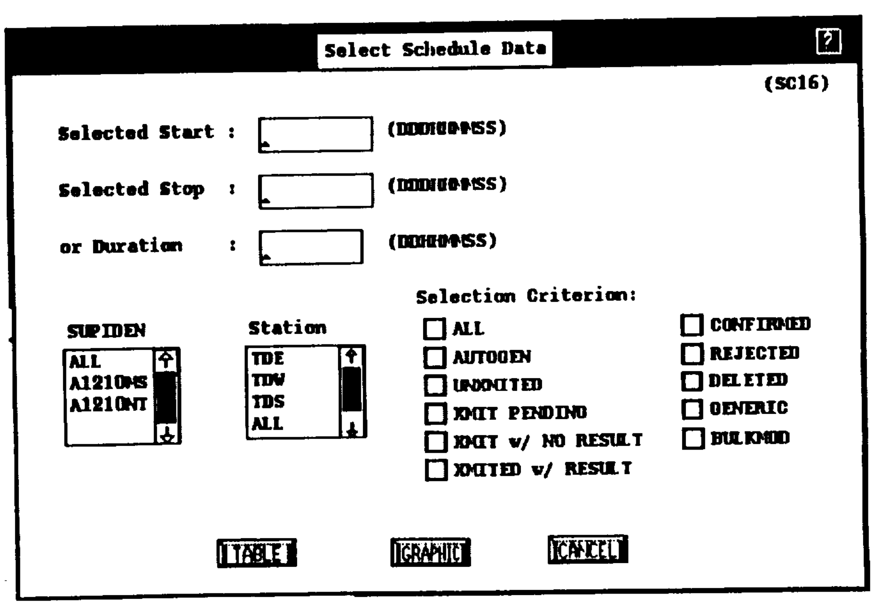
## Select Schedule Data Panel

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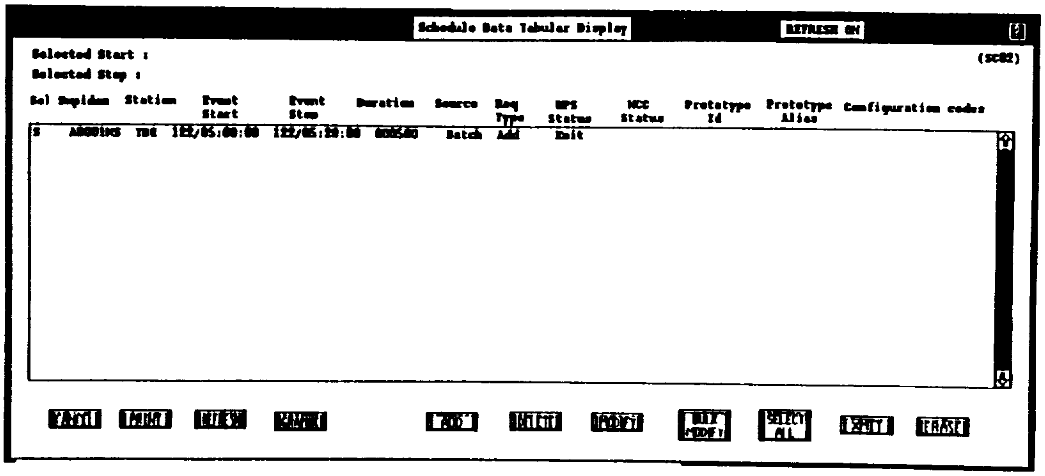
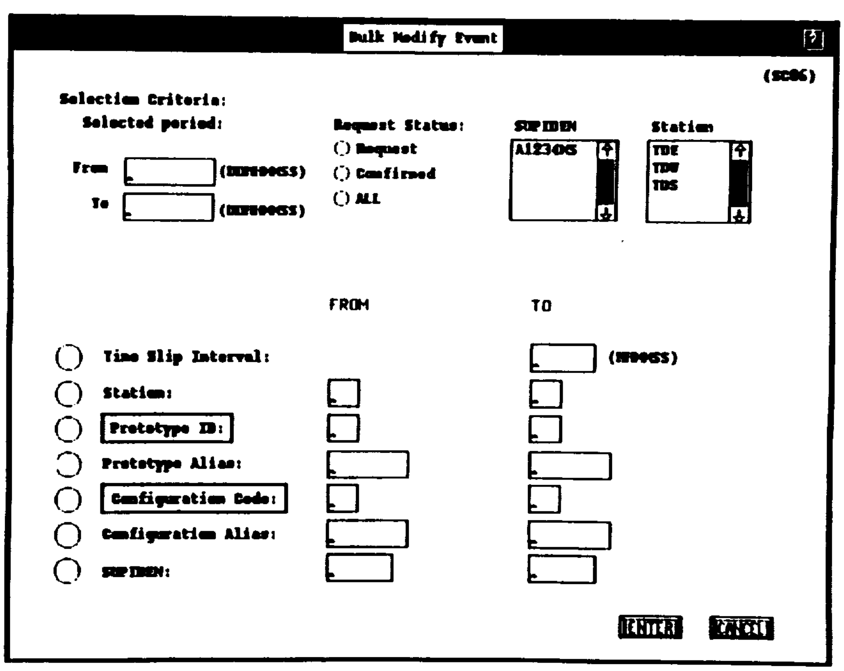
00-14

# Schedule Data Tabular Display Panel







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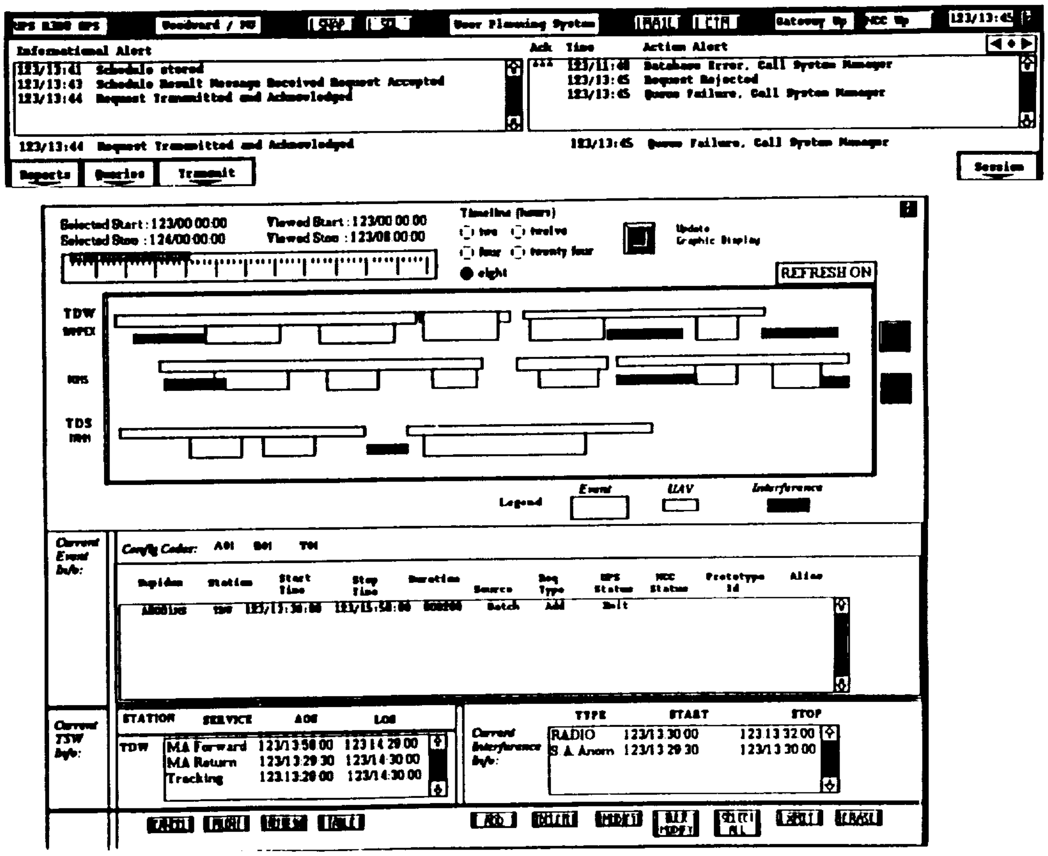
Code 520

# Schedule Data Graphic Display Panel




00-17

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# Graphic scheduling aid design

Allow single or multiple event mofidication, deletion or insertion

Present tabular information in an easy to interpret format

Show interrelationships between services, events, interference and intermission conflicts for resources.

Provide selection / multiple selection via mouse and control key

Provide visual cues to differentiate TSWs, Events and Interferences.

# Schedule Data Graphic Display

- Select/deselect single or multiple requests by clicking on graphic requests
- Provide action buttons (see select data tabular display panel)
- Change to tabular scheduling (Table option)
- Display TSW information for services related to a selected request (from the current event information window)

- Select display range based on viewed time
  - Select range of display using Radio buttons
  - Select start time using Viewed Start input field
  - Input Viewed Stop to override the timeline radio button set (optional)
  - Update graphic display to incorporate changes using Update Graphic Display button
    - Graphic display configuration depends on the number of missions and TDRSs used
    - Scroll graphic display using the slider mechanism

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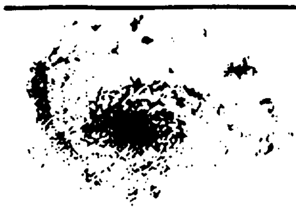


SPIKE

# SPIKE: AI SCHEDULING TECHNIQUES FOR HUBBLE SPACE TELESCOPE


**Mark D. Johnston**

GSFC
13 December 1990

Space Telescope Science Institute • Advance Planning Systems Branch
3700 San Martin Drive Baltimore MD 21218

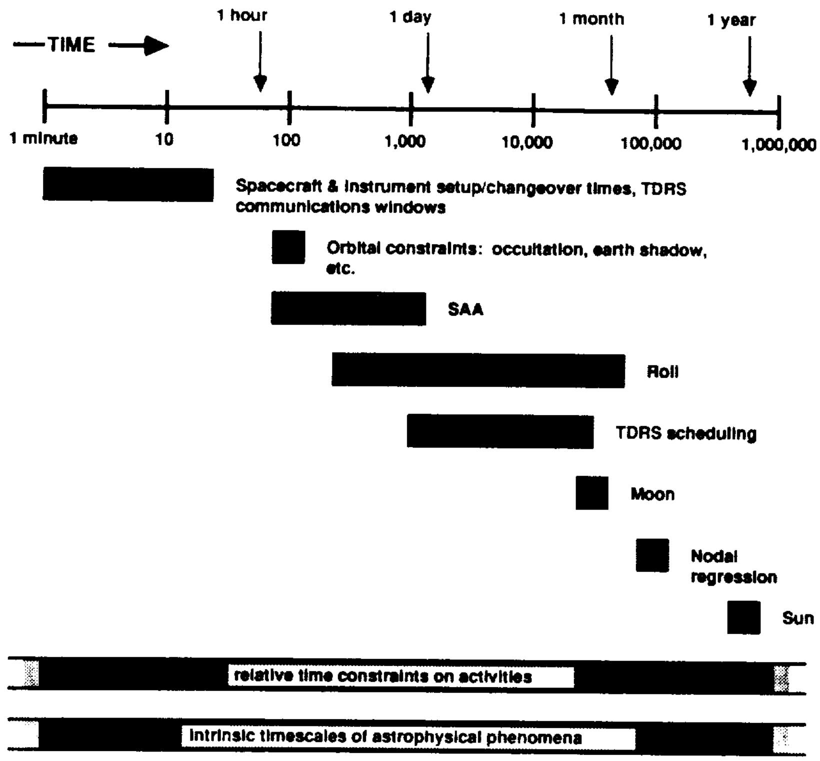

P-1

## Domain

Hubble Space Telescope (HST) observation scheduling

- HST launched by NASA in April 1990
- 15 year lifetime, low earth orbit (95m period)
- science operations for NASA by Space Telescope Science Institute (STScI) at Johns Hopkins Univ., Baltimore
- HST scheduling is a large problem:
  - ~10,000-30,000 observations/year to be scheduled
  - large number of interacting constraints (~ 10 per observation)
    - operational
    - resource
    - scientific
  - enormous range of constraint timescales (seconds to many months)

## HST Constraint Timescales




P-3

p. 3

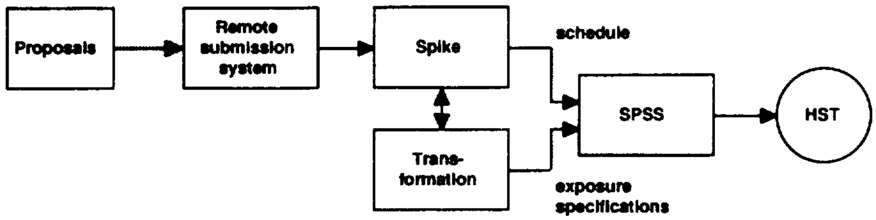
## HST Scheduling

- Predictive scheduling is required by design of spacecraft, ground system
- Pool of observations is intentionally oversubscribed (by about 20%)
- Primary goal is to maximize scientific efficiency of observatory
  - maximize utilization on highest-priority science
  - maximize quality of data taken
- Uncertainty is major problem (orbit, availability of guide stars)
- Spike is a task-oriented scheduler developed by STScI
  - Development started early 1987
  - Current focus: long-range scheduling (one year or more) to resolution of ~days
  - Spike is currently operational and working on flight schedules for period following on-orbit checkout

    Long-term scheduling is on hold pending revision of observing proposals for spherical aberration

## Spike Overview

- Spike draws on two major themes in AI research & applications:
  - constraint satisfaction techniques (search, constraint preprocessing)
  - weight-of-evidence combination for uncertainty reasoning
- Several strategies adopted to decompose problem
- Data flow schematic: from observing proposals to command loads




- Spike was designed to support two major modes of use:
  - automatic (offline) scheduling
  - graphical interaction by users, to make scheduling decisions and diagnose scheduling problems

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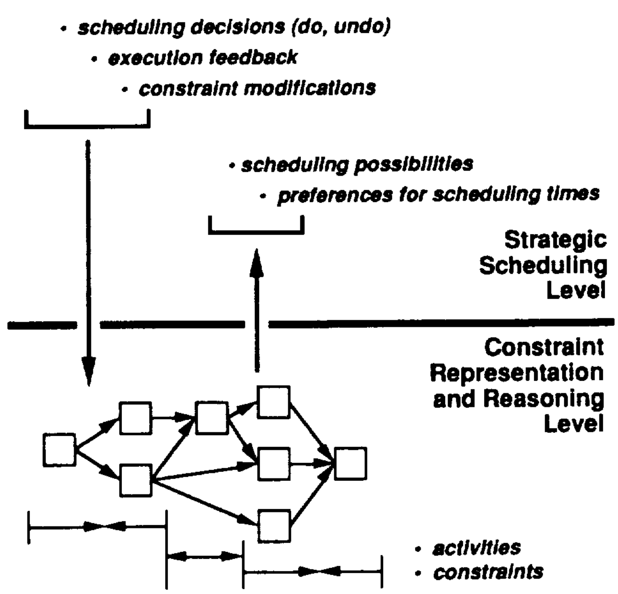
*p. 5*

## Spike Architecture

- Spike Architecture:
  - low-level constraint representation & propagation
  - higher-level strategic scheduling (search) modules






P-6

## Constraint Representation & Reasoning

- Temporal constraints and preferences are captured by "suitability functions" based on scheduling expert's assessment:

  the degree of preference for scheduling $A_i$ at t due to constraint $\alpha$,

  given that $A_j$, $A_k$, ... scheduled at $t_j$, $t_k$, ..., is $S_i^{\alpha}(t; t_j, t_k, ...)$

- Suitability functions are defined for constraints and derived for tasks
- Projected to functions of time (only) by taking max over possible scheduling times of related activities
- Combined by multiplication: value of 0 means scheduling forbidden, >0 indicates degree of preference
- Combination is formally identical to weight-of-evidence combination in uncertainty reasoning except for special role of overwhelming evidence against scheduling at certain times (S = 0)

P-7

p. 7

## Suitability Functions (cont.)

- Task suitabilities are computed by iteration corresponding to:
  node consistency on network of constraints
  + implications of cumulative scheduling decisions
- Value of suitability function informs scheduling agent:
  - times excluded due to strict constraints
  - measure of combined degree of preference due to preference constraints
- For computational efficiency, suitability functions in Spike are represented by piecewise-constant functions of time
  - closed under all important operations
  - no discretization of time or suitability values required
    i.e. no arbitrary limits on time granularity

P-8

## Use of Suitability Functions by Scheduling Agent

- **Identify unschedulable activities: $S_i(t) = 0$ for all t**
- **Measure of optimality of schedule: $\prod_i S_i(t_i)$**
- **Measure of potential inherent in partial schedule:**

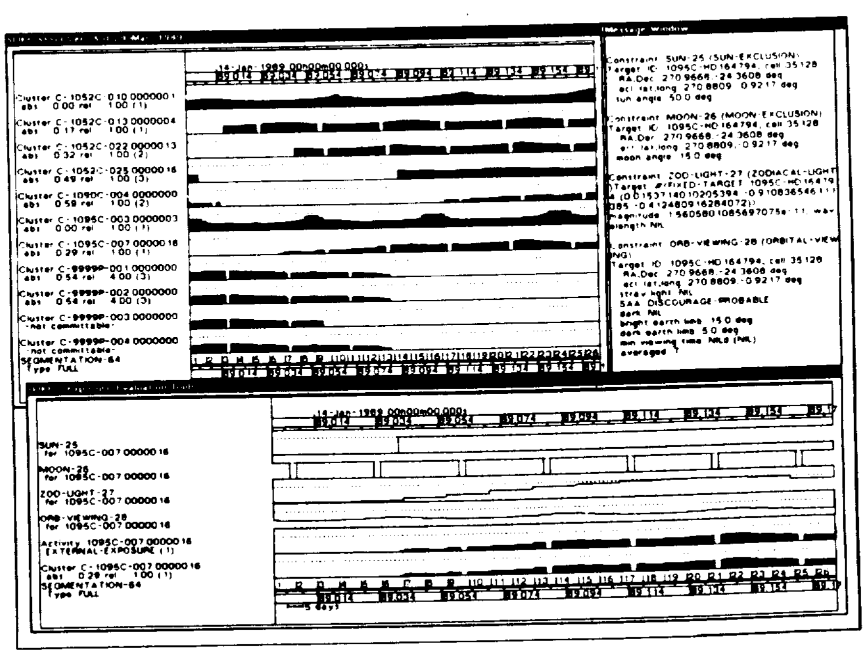
  **$\prod_i \max S_i(t)$ indicates best that can be achieved**

  - **use to guide search, i.e. explore most promising alternatives first**
- **Explanation: <u>why</u> an activity is unschedulable at t can be determined by examining contributions of constraints to suitability**
  - **guide backtracking at deadends**
  - **give users insight into problem cases: Spike provides graphical display of contributions to strict and preference constraints**

P-9

*p. 9*

## Spike Screen Example





P-10

## Advantages of Suitability Function Framework

- Uniform means for simultaneously representing strict (yes/no) and preference constraints
- Framework can represent naturally:
  - trade-offs among preferences
  - uncertainty in predicted scheduling conditions (e.g. high risk ⇒ low suitability)
  - implications of scheduling decisions as they are made
  - implications of task execution as schedule is implemented
- Identify inconsistent constraints & unschedulable activities as soon as feasible
- No times excluded unless in violation of strict constraints or a consequence of prior scheduling decisions
- No bias about future scheduling decisions
- Generally declarative representation ⇒ easy to modify

P-11

p. 11

## Limiting Search & Constraint Propagation

Techniques used by Spike:

- Demand-driven constraint propagation
  - i.e. only upon reference to quantities which require constraint consistency
- Time: schedule from coarser to finer time resolution -
  - Formulate constraints to capture essential behavior at relevant timescales
  - Segment scheduling period into sub-intervals, commit, then decompose
- Path consistency -

  For some types of binary constraints it is possible to perform path-consistency before scheduling
  - dramatically speeds constraint propagation during scheduling search
  - identify path-inconsistent constraints before scheduling starts
  - drawback: reduced explanatory capabilities

## Limiting Search (cont.)

- Activity clustering -

  Sequence activities into clusters to commit as single entities, considering:

  - absolute time constraints
  - binary relative time constraints in path-consistent form
  - heuristics for ordering preferences
    (e.g. constraint strictness, minimize state change overhead times)

  – collapse partially-redundant constraints to their conjunctions

  – pull activity constraints up to cluster level and save

*Path Consistency + Activity Clustering ⇒*

*> order of magnitude reduction in size of problem*

P-13

*p. 13*

## Scheduling Search

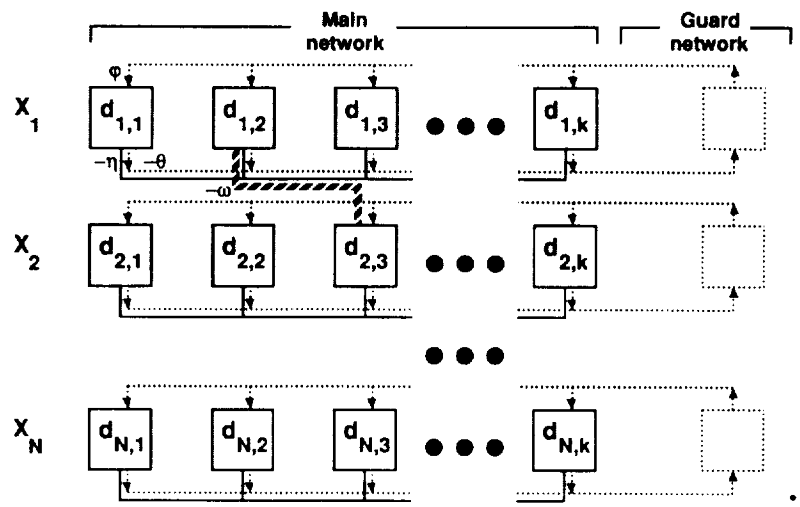
Several methods provided: all use same underlying constraint representation/propagation mechanism:

- Greedy algorithms
- Backtracking search
- Stochastic ("Neural network")
- Repair methods

Preliminary investigation of re-scheduling algorithms conducted (i.e. where schedule stability is an important goal)

## Stochastic Search

- Developed in collaboration with H.-M. Adorf of Space Telescope - European Coordinating Facility
- Motivated by Hopfield discrete neural network model (but can be formulated as backtracking search using network only for bookkeeping)
- Discretize time: network element represents decision to schedule an activity in a time interval
- Network biases and connections derived directly from suitability functions

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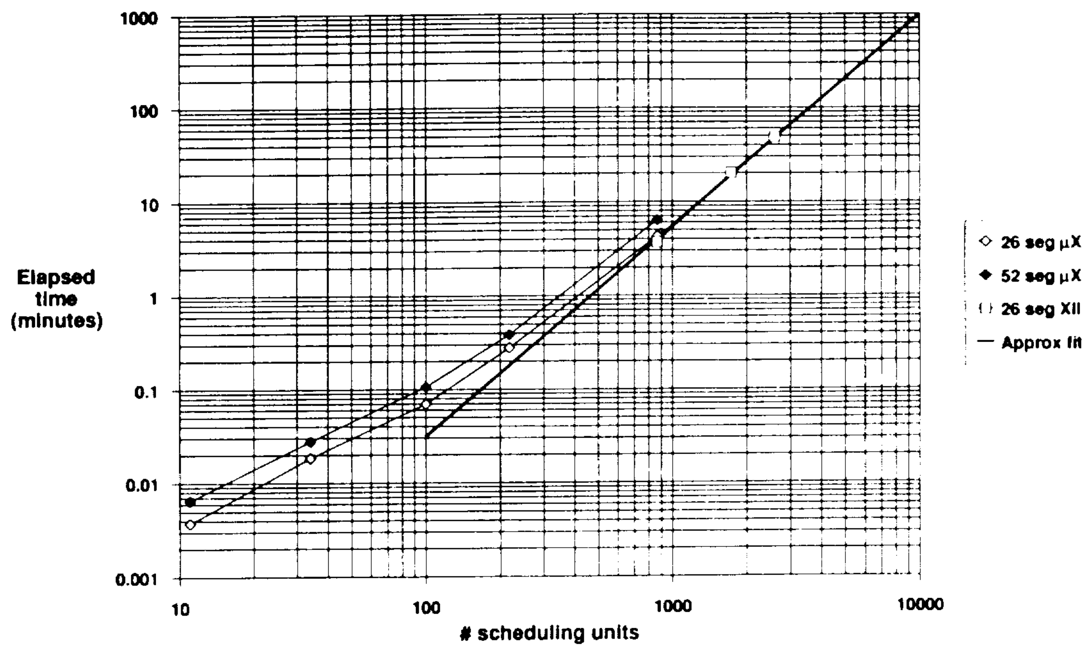
*p. 15*

## Stochastic Search (cont.)

- Couple to additional networks representing
  - constraint that activity must be scheduled sometime
  - resource (capacity) constraints
- Approach is well-suited for satisficing search where optimization is desired but infeasible
- Interesting characteristics of search:
  - backtracking from deadends and extending partial assignments are simultaneous competing processes
  - tends to maximize overall degree of preference represented by suitability functions
    - i.e. schedules tend towards optimal
  - permits temporary constraint inconsistencies but will not terminate until there are none
  - may not converge (stop and restart)
- By far most effective search strategy in Spike to date
- Performance demonstrated to be adequate for large-scale HST problem

**Neural Network Search Timings**




P-17

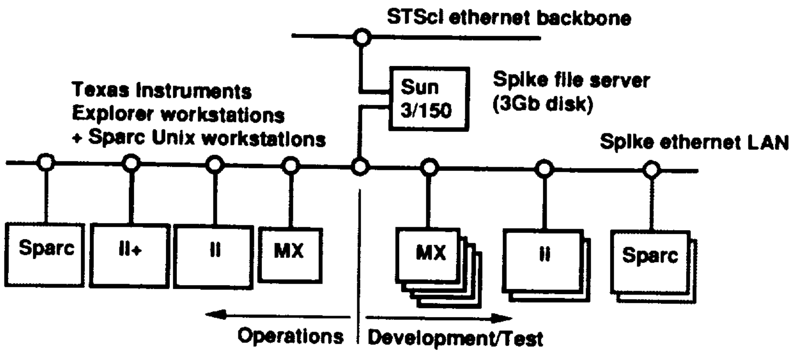
## Repair Methods

- Recent work is concentrating on repair methods
  - analysis of neural network operation has isolated several heuristics that explain its success, e.g. min-conflicts
  - theoretical analysis of model problems has identified other heuristics that further improve search performance
- Repair heuristics can be applied in framework that preserves performance of neural network but adds flexibility
- Ideal for reactive re-scheduling
- Machine-learning techniques are being applied to repair methods to "learn" best strategies

P-18

## Implementation

- CommonLisp, old Flavors, conversion to CLOS just completed
- CommonWindows for user I/F
- Developed and operated on TI Explorer Lisp machines




- Unix port of core system & user I/F completed December 1989 (using X-windows based CommonWindows); plan for operations migration to Sparcstations over next year

P-19

*p. 19*

## Status

- Spike is in operational use at STScI for scheduling the period following HST instrument checkout and calibration
  - long-term scheduling has been delayed by optics problems
  - Spike is being used for scheduling feasibility checking on shorter timescales
- Use on other problems has been demonstrated:
  - Spike now running at UC Berkeley for scheduling NASA's Extreme Ultraviolet Explorer ('92)
  - MIT plans to use Spike for scheduling X-ray Timing Explorer mission ('94)
- Ongoing work at STScI on performance improvements, repair & rescheduling, short-term scheduling, portable version



P-20

*p. 20*

N92-11055

# Intelligent Perturbation Algorithms for Space Scheduling Optimization

Space Network Control Conference on
Resource Allocation Concepts and Approaches
Goddard Space Flight Center
December 12-13, 1990

by

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Q-1



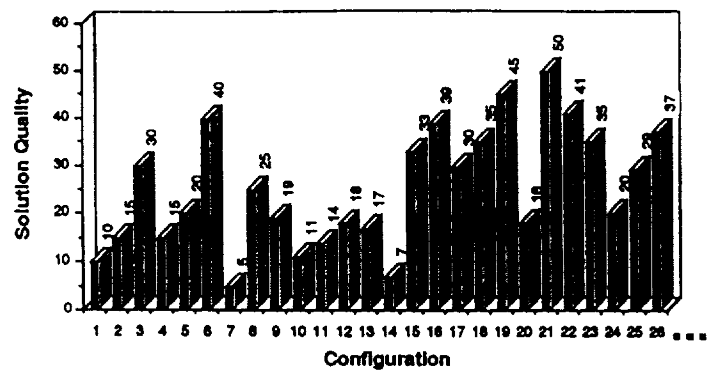
## Why Optimize?

Optimization of planning, scheduling, and manifesting:

- Saves Time
- Saves Money
- Increases Fulfillment of Mission Goals

Q-2

## Searching a Discrete Configuration Space




- Configuration space is discrete and exponentially large
- Hill climbing is a reasonable approach, but terms such as "hill", "neighborhood", and "direction" are not obviously defined
- Typically, one would want to find a good solution by looking at about only 100 out of n! possible solutions





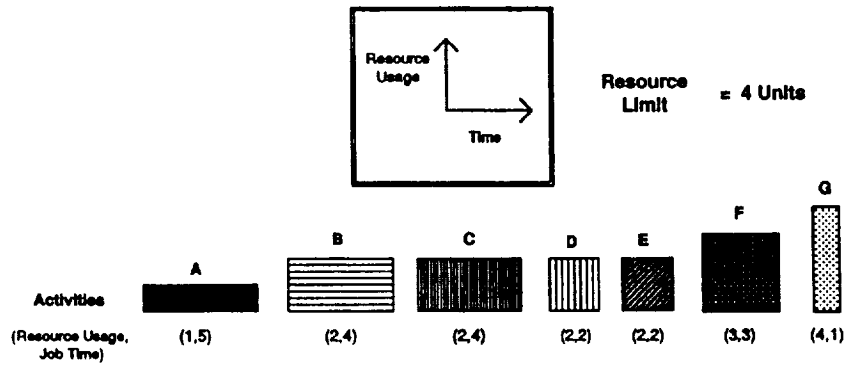


## Heuristics Algorithms Are Used For Optimization

- What is a heuristic?
  - -- A rule which usually finds a solution that is good but not always optimal
- Why use heuristics?
  - -- Realistic scheduling problems are NP-Hard

  ⇒ Finding an exact solution is not realistic
- Polynomial heuristics are used instead of exponential exact techniques to make optimization feasible

## Use of Heuristic Methods on a Sample Scheduling Problem



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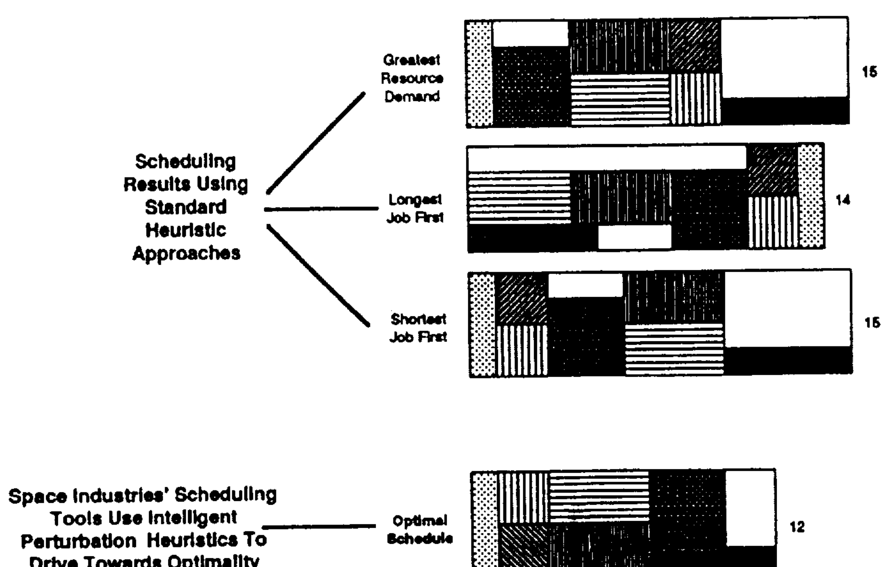
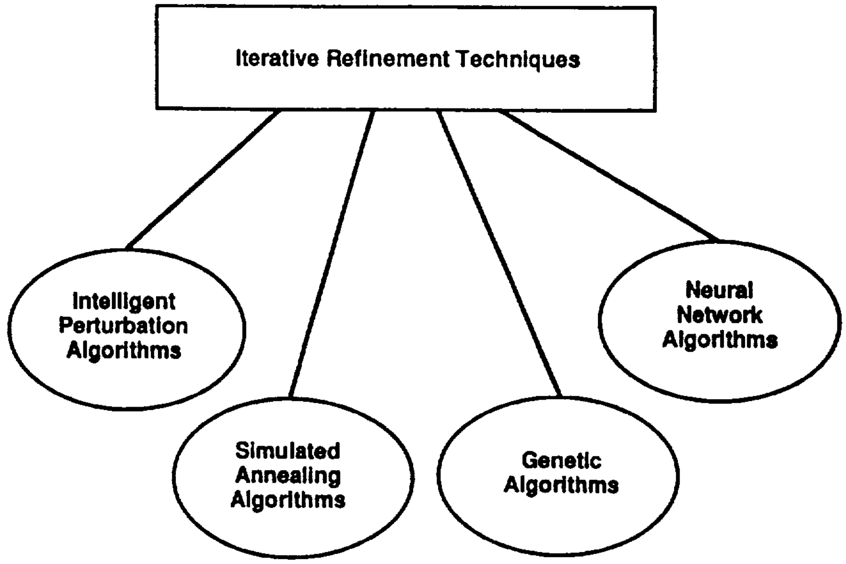
## Use of Heuristic Methods on a Sample Scheduling Problem (Continued)



## Intelligent Perturbation Algorithms are Iterative Refinement Techniques




**Unlike these other methods, Intelligent Perturbation Algorithms rely on search steps that are "intelligent" rather than random to systematically and quickly find good solutions**

Q-7

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## Properties of a Good Iterative Search Operator

- Operator should be able to potentially span the search space in a small number of steps
- Computational overhead of iterations should be small compared to cost of producing a schedule
- Search should have a randomized component (or some other provisions) for avoiding loops and breaking away from local optima

Q-8

## Intelligent Perturbation Algorithm (Dispatching Example)

1) Rank activities (tasks, operations) by priority

2) Create initial schedule by dispatching using ranked ordering

3) Adjust rankings using perturbation operator to accommodate unscheduled objectives

4) Create new schedule by dispatching using new ranked ordering

5) Repeat steps 3 and 4 until search cutoff is reached

6) Use best schedule found during search



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## Perturbation Operator Attributes (Dispatching Example)

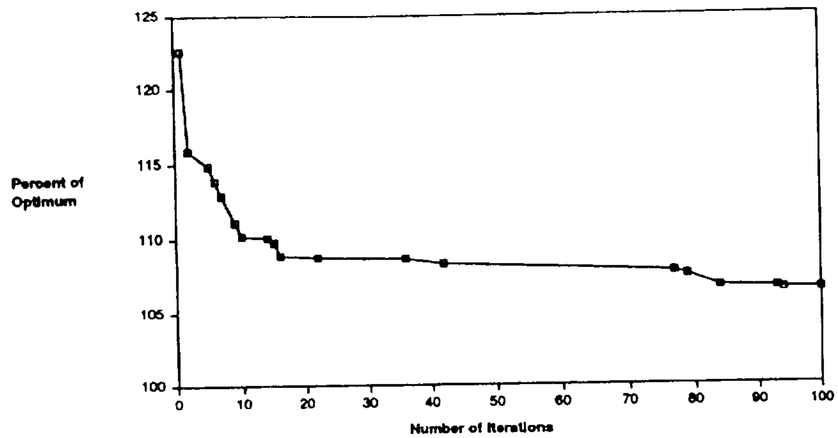
- Increases rankings of activities not satisfactorily scheduled on the previous iteration

- Increases rankings of bottleneck activities

- Parameters can be adjusted to fit the structure of the particular scheduling problem

- Choice of parameters is key to finding good schedules

## The Intelligent Perturbation Algorithm




- Standard Methods Give Solutions 23% Worse Than Optimum on Sample Test Problems
- Intelligent Perturbation Search Techniques Improve Solutions to Within 10% of Optimum In 10 Search Steps

Q-11



### Scheduling Implementations Using Intelligent Perturbation Algorithms Include:

- Optimization of scheduling scenarios for SLS-1 and IML-1 pre/postflight Baseline Data Collection Facility (BDCF) sessions by the MIT Man-Vehicle Laboratory
- Optimization of Space Station *Freedom* Design Reference Mission (DRM) scheduling
- Optimization of planned operation of customer payloads aboard the Industrial Space Facility (ISF)
- Optimization of ISF-TDRSS command scheduling
- Optimization of Spacelab Stowage for SLS Mission by GE Government Services
- Optimization of petrochemical plant scheduling by The Johnson Group

In addition, independently developed algorithms used at JPL and NASA AMES use directed iterative refinement methodologies

Q-12

## Major Advances in Scheduling Capabilities

| | 1980s | 1990s |
|---|---|---|
| Scheduling Optimization | Iterative Search Techniques | Parallel Processing |
| Scheduling Software Development | Mouse-Window Style Interactive User-Friendly Interfaces | Object-Oriented Programming Environments |

Q-13

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## The Prototype ISF Experiment Scheduler

Q-14

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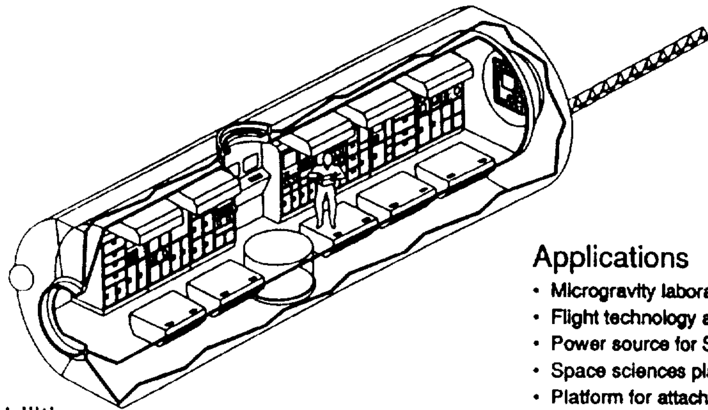
# Industrial Space Facility (ISF)



## Capabilities

- Permanent presence in space
- High quality microgravity environment ($10^{-6}$ to $10^{-7}$ g)
- 3 to 6 months mission duration
- Power-rich environment
- Accommodation of state-of-the-art automation and robotics
- International Space Station rack compatibility

## Applications

- Microgravity laboratory
- Flight technology and operations testbed
- Power source for Spacelab and other Shuttle missions
- Space sciences platform for observation and measurements
- Platform for attaching external payloads
- "Interim Step" to International Space Station and International man-tended free-flyers
- Processing/manufacturing facility

The first permanent, man-tended commercial space facility designed for R&D, testing and, eventually, processing in the space environment.



Q-15

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# SPACECRAFT Planning and Scheduling Systems and Services

## Motivation

The Prototype ISF Experiment Scheduler was developed to:

- Establish/assess design requirements
- Assure compatibility among payloads
- Formulate a pricing policy for the ISF
- Optimize utilization of scarce resources; limited availability and high cost makes optimization critical. Schedules which make best use of available resources are typically more satisfying to customers because they allow additional experiment runs.

**Flexible and efficient manifesting, scheduling, and operations capabilities are central to the customer oriented commercial approach of the ISF project.**



Q-16

## Objectives

The primary goals of the Prototype ISF Experiment Scheduler project were:

- Development of a prototype multi-variable scheduling tool for making manifesting decisions and resource usage assessments
- Rapid design and implementation of the system in a very short time period
- Building the system with an intuitive and graphical interface on a personal computer (Apple Macintosh)

**The number of complex experiments and real-time changing constraints aboard the ISF (or many other spacecraft) make it virtually impossible for a human scheduler to manually find a timeline which simultaneously maximizes the utilizations of multiple resources.**




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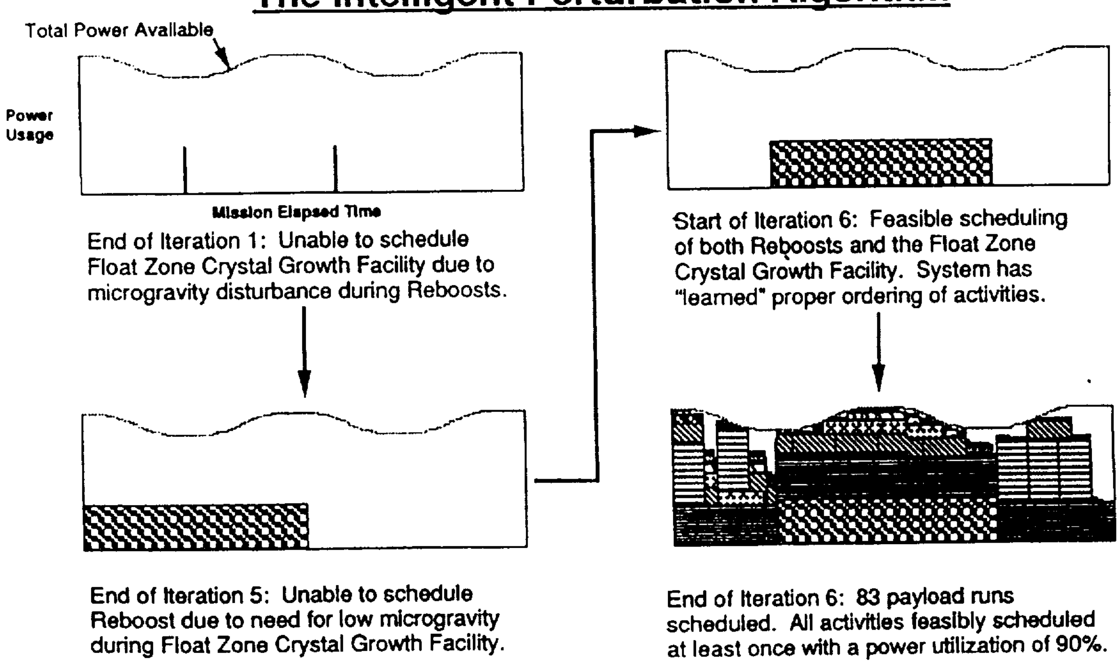
## The Intelligent Perturbation Algorithm



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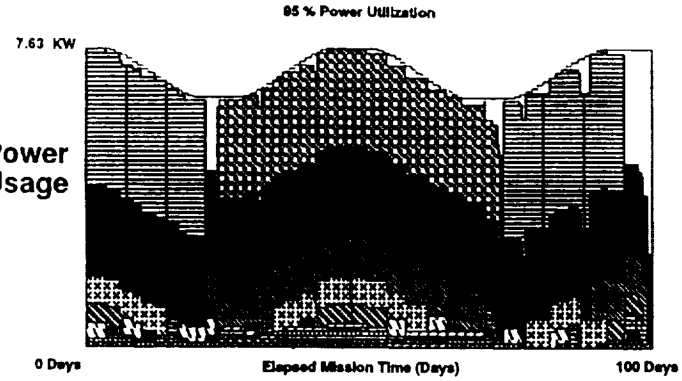
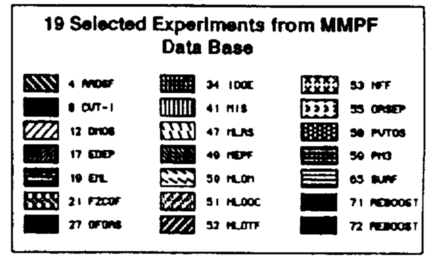
## Optimized Schedule (Max Revenue)

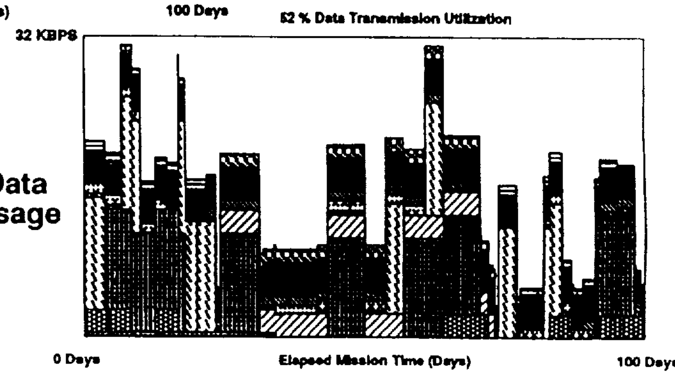
Power Usage




| ID # | Experiment Name | Runs Scheduled | Max Runs Requested |
|---|---|---|---|
| 4 | Advanced Automated Directional Solid. Fur. | 4 | 8 |
| 8 | Chemical Vapor Transport - I | 8 | 6 |
| 12 | Diffusive Mixing of Organic Solutions | 1 | 2 |
| 17 | Electrodeposition | 1 | 2 |
| 19 | Electromagnetic Levitator | 7 | 8 |
| 21 | Float Zone Crystal Growth Facility | 1 | 2 |
| 27 | Gradient Furnace for the Get-Away-Special | 6 | 8 |
| 34 | Isothermal Dendritic Growth Experiment | 7 | 8 |
| 41 | Magnetic Isolation System | 6 | 7 |
| 47 | Mono-disperse Latex Reactor System | 6 | 6 |
| 49 | Multiple Experiment Processing Facility | 6 | 6 |
| 50 | Non-Linear Optical Monomers | 1 | 3 |
| 51 | Non-Linear Optical Organic Crystals | 1 | 3 |
| 52 | Non-Linear Optical Thin Films | 1 | 3 |
| 53 | Normal Freezing Furnace | 4 | 7 |
| 55 | Organic Separations | 2 | 2 |
| 56 | Physical Vapor Transport of Organic Solids | 8 | 6 |
| 59 | Polymer Microstructure and Morphology | 6 | 8 |
| 65 | Space Ultra-Vacuum Research Facility | 8 | 8 |
| 71 | Reboost | 1 | 1 |
| 72 | Reboost | 1 | 1 |
| Total | | 84 | 118 |

Data Usage




Q-19

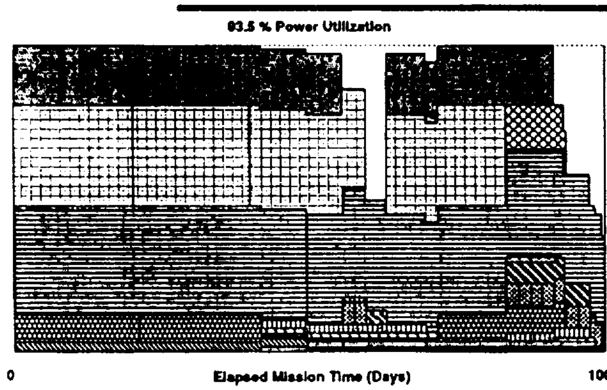
SPACE INDUSTRIES INTERNATIONAL INC.

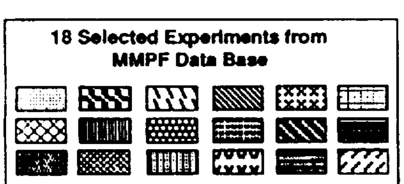
**SPACECRAFT** Planning and Scheduling Systems and Services

## Multi-Variable Optimization

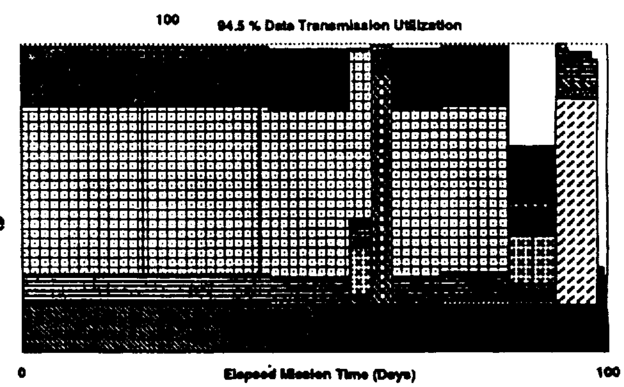
**ISF Payload Scheduling**

Power Usage




Data Usage




Q-20

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## Prototype ISF Experiment Scheduler - Results

- Allows easy assessment of manifest changes, and comparison of relative revenues and resource utilizations among different sets of manifested payloads.
- Run time on a Macintosh II is about 45 seconds per iteration. Graphics require 2/3 of this time. Typically 30 iterations are sufficient to generate very good schedules.
- Core of the scheduler was built in a few days, and the input and output interfaces were built in a couple of weeks.

**As the design and operational characteristics of the ISF and its associated payloads become better defined, this prototype will serve as the basis for the development of higher-fidelity tools.**

**Initial research has looked at methods of providing dynamic rescheduling of ISF telescience operations in response to real-time investigator requests.**

Q-21

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## Space Station Design Reference Mission Scheduling

- Crew availability was the limiting factor in the scheduling of this DRM. Optimization increased crew utilization by more than 106 hours during the 2 week mission.
- NASA recently published a rate of 100K/crew-hour for commercial operations aboard the Space Shuttle. This translates to lost opportunity costs of 5.3 million per week if optimization is not used to fully utilize crew available for payload operations.

| | Runs | Crew (crew-hr) | Power * (kw-hr) | Power** (kw-hr) | Activity Density** |
|---|---|---|---|---|---|
| Requested | 422 | 539 hr, 10 min (118.1%) | 11474.7 (136.6%) | | |
| Available | | 456 hr, 30 min (100.0%) | | 8400.0 (100.0%) | |
| NASA Provided Baseline | 272 | 333 hr, 35 min ( 73.1%) | 9746.3 (116.0%) | 6685.7 ( 79.6%) | 22.7 |
| Space Industries Result | 387 | 440 hr, 10 min ( 96.4%) | 11047.3 (131.5%) | 6673.7 ( 79.4%) | 25.0 |

* for the entire schedule
** in initial 2 weeks only

Q-22

## ISF - TDRSS Command Scheduling Demonstration

- Demonstration scenario conducted over a 24 hour (16 orbit) period
- 16 tasks (some repetitive) were considered
- ISF power available was limited to 7 kilowatts at any time
- 2 TDRSS available. TDRSS is accessible 58.9 minutes (65.1%) per orbit
- Downlink via TDRSS is in 1 of 5 exclusive formats. Multiple tasks may be performed simultaneously as long as they do not require differing formats.

Almost all tasks had unique and complex constraints which could not easily be accommodated using a standardized input interface.

**Required a radically different approach to representing constraints and building a schedule.**

Q-23

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## Example Task: Communications Check

**Duration:** 10 minutes, consisting of 5 consecutive 2 minute segments

**Power Requirements:** 200 W for the full 10 minutes

**Downlink Requirement:** Each of the 5 segments must be in a different format (A, B, C, D, and E) so that each format is used once. The order is not important.

**Repititions:** Should occur (i.e., the starting time should fall) once per orbit (as measured from time zero).

Q-24

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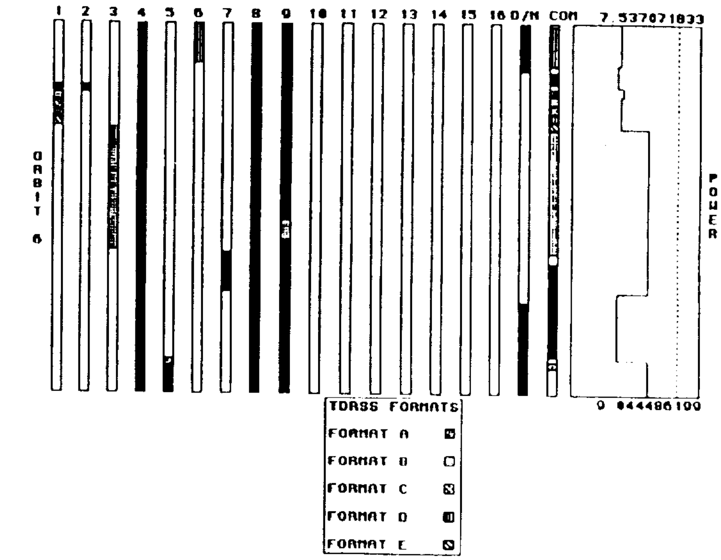
## SPACECRAFT Planning and Scheduling Systems and Services

### ISF - TDRSS Command Scheduling Demonstration - Orbit 6




Q-25

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# Conclusions

- Intelligent Perturbation Algorithm approaches have been successfully implemented in numerous scheduling systems
- Optimization can result is significant cost savings and can maximize capabilities when resources are limited
- Successful implementation of a scheduling system requires an in-depth understanding of space operations, optimization techniques, and building user-friendly software that is intuitive and easy to use

Q-26

N92-11056



# POLYNOMIAL OPTIMIZATION TECHNIQUES FOR ACTIVITY SCHEDULING

## OPTIMIZATION BASED PROTOTYPE SCHEDULER

Surender Reddy
Computer Sciences Corporation

December 1990

**Space Network Control Conference on Resource Allocation Concepts and Approaches**
Goddard Space Flight Center, Greenbelt MD



R-1



# Agenda

- Need and Viability of Polynomial Time Techniques for SNC
- Intrinsic Characteristic of SN Scheduling Problem
- Expected Characteristics of SN Resource Schedules
- Optimization Based Scheduling Approach
- Single Resource Algorithms
- Decomposition of Multiple Resource Problems
- Prototype Capabilities
- Prototype Test Results
- Computational Characteristics
- Prototype Characteristics
- Some Features of Prototyped Algorithms
- Some Related GSFC References



R-2

## Need and Viability of Polynomial Time Techniques for SNC

- **Need for Efficient Scheduling Techniques such as Polynomial Time Algorithms**

  Subjective scheduling decisions in an environment such as the SN are necessary. However, producing a good initial schedule based on subjective analysis is very labor intensive, impractical and unnecessary. Initial schedules based on computationally efficient approaches optimizing a general objective such as maximizing requests can be the basis from which a final schedule can be evolved through changes and fine tuning based on subjective analysis and human interaction.

- **Viability of Polynomial Time Algorithms for SNC**

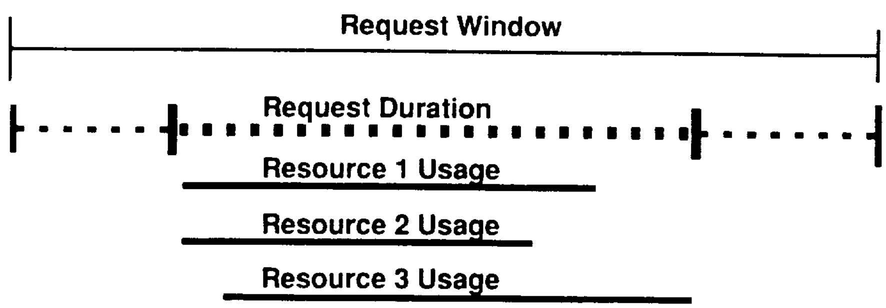
  Recent R & D effort at GSFC has shown that polynomial time algorithms for SN resource scheduling are viable and practical.



POLYNOMIAL OPTIMIZATION TECHNIQUES FOR ACTIVITY SCHEDULING
Space Network Control Conference on Resource Allocation Concepts and Approaches

## An Intrinsic Characteristic of SN Scheduling Problem

Highly-coupled usage of resources for each request, i.e., Each request uses all resources it requires either simultaneously or in the immediate time frame



# Expected Characteristics of the Schedule

Tight coupling of resource usage tends to force schedules with the following characteristics

- General sequence (time-order) of scheduled requests is nearly same for all resources
- Schedule for high-demand resources implicitly control the schedule for resources with low - demand

A multiple resource-usage request which is rejected when attempted to be scheduled independently on a low demand resource type is highly unlikely to be scheduled on a high-demand resource type.





# Optimization Based Scheduling Approach

A combination of optimization and heuristic techniques

- Optimal and near optimal single resource scheduling using polynomial time optimization algorithms
- Heuristic reasoning for decomposing multiple resource problems into a series of single resource problems suitable for application of the polynomial time single resource algorithms

# Single Resource Algorithms

- **First Algorithm (Does not consider activity priorities)**
  - — Maximizes the number of scheduled activities
  - — Generates sequence of scheduled activities with reduced windows
  - — Developed earlier last FY under SEAS task 20-122
- **Second Algorithm (Considers activity priorities)**
  - — Maximizes the priority weighted number of scheduled activities when there are two priorities
  - — For problems with > 2 priorities, algorithm is applied to series of two priority problems
  - — Generates sequence of scheduled activities with reduced windows



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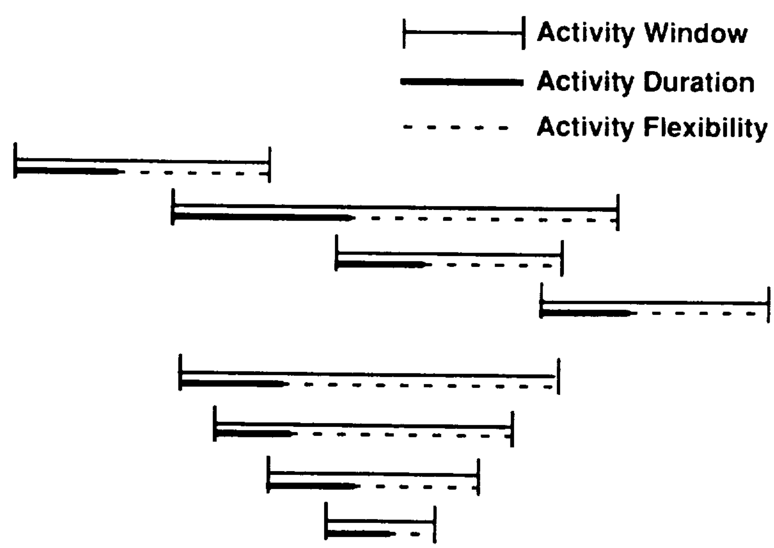
# First Single Resource Algorithm

Provides ...

Optimal Solution when windows exhibit (Cascade Structure)

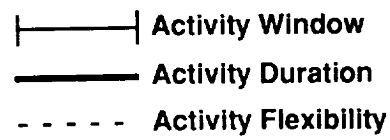



Optimal Solution when windows exhibit (Triangular structure)

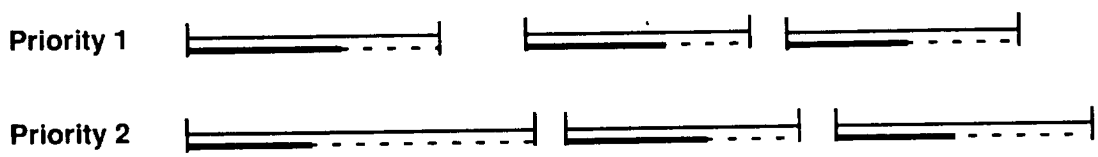
Near Optimal Solution when windows exhibit

A general unrestricted structure

# Second Single Resource Algorithm




Provides optimal solution for a two priority problem when activity windows within each priority are non-overlapping






R-9

POLYNOMIAL OPTIMIZATION TECHNIQUES FOR ACTIVITY SCHEDULING
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# Decomposition of Multiple Resource Problems

Schedule resources in increasing order of usability

Reason:

Given: Resources A and B

Activity set S(A) — Schedulable only on A

Activity set S(B) — Schedulable only on B

Activity set S(A or B) — Schedulable on A or B

Scheduling as many of activities in S(A or B) as possible on least usable of A and B tends to maximize the availability of resources for highly resource specific activities



R-10

# Decomposition of Multiple Resource Problems

(CONTINUED)

Example: S(A) = 100 S(B) = 20 S(A or B) = 20

Scenario 1—Schedule A first and schedule B second

70 of S(A) and 10 of S(A or B) scheduled on A

20 of S(B) and 10 of S(A or B) scheduled on B

Total scheduled: 100

Scenario 2—Schedule B first and schedule A second

20 of S(B) and 19 of S(A or B) scheduled on B

90 of S(A) scheduled on A

Total scheduled: 129

Scenario 2 maximizes the scheduled activities





# Prototype Capabilities

Scheduling of Specific and Generic Requests for:

- Tracking and Data Relay Satellites
- Deep Space Network
- Ground Network
- For Combination of Space and Ground Resources

# Prototype Test Results

| | Total Reqstd Events | Scheduled Events | | Upper Bound | Wall Clock Time (Min.) |
|---|---|---|---|---|---|
| First Algorithm (Disregard Priorities) | 1584 | 1478 | 93.3% | 98.7% | 3 .25 |
| | 2960 | 2415 | 81.6% | 86.% | 21.1 |
| Second Algorithm (Consider Priorities) | 1594 | 1499 | 94.6% | 98.7% | 18.5 |

Tested on

- PC/AT running at 12 MHz without a math coprocessor





# Computational Characteristics

Analytically determined computational requirements of the prototyped algorithms is a 3rd order polynomial of the number of activities

$t = k * n^3$

For n=1584

$t = 3.25$ implies $k = (1584)^{-3} * (3.25)$

For n = 2960

$t = (1584)^{-3} * (3.25) * (2960)^3 = 21.2$ Min

# Prototype Characteristics

- COMPUTER: PC or PC (AT)
- LANGUAGE: MS-FORTRAN
- NUMBER OF LINES OF SOURCE CODE : 2000 Approx.
- EXECUTABLE MODULE: 520 Kbytes
- CAPACITIES: 8 Resource types
  10 Resource Groups (TDRS/Ground Stations)
  12000 Resource Intervals
  3200 Instances



POLYNOMIAL OPTIMIZATION TECHNIQUES FOR ACTIVITY SCHEDULING
Space Network Control Conference on Resource Allocation Concepts and Approaches

# Some Features of Prototyped Algorithms

Prototyped algorithms can be used for:

- Initial batch scheduling
- Batch rescheduling while limiting changes to any combination of:
  - — restricted deletions for selected instances
  - — restricted non-deletion schedule changes to selected instances
  - — allowable deletion of selected instances

# Some Related GSFC References

- Optimization Based Prototype Scheduler
  DSTL-90-024, Available December 1990
- Single Resource Scheduling with Ready and Due Times
  DSTL - 89 - 024, December 1989
- A Study of Optimization Techniques for Activity Scheduling
  DSTL - 89 - 019

N92-11057

# Range Scheduling Aid (RSA)

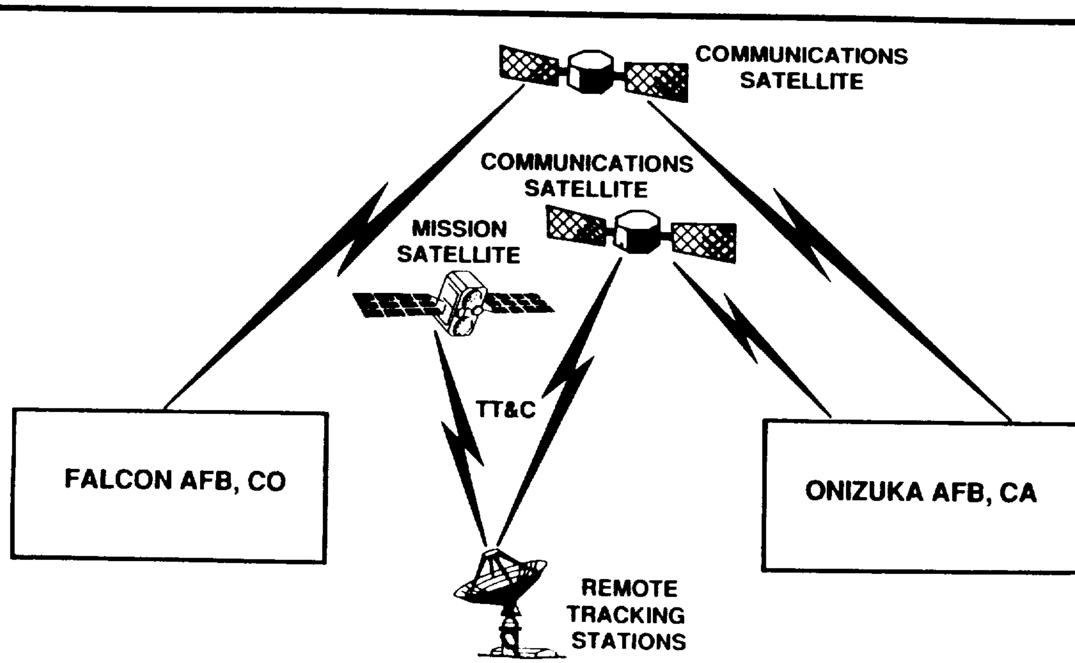
J. R. Logan and M. K. Pulvermacher

13 December 1990

MITRE

S-1

## Satellite Control Network




MITRE



S-2

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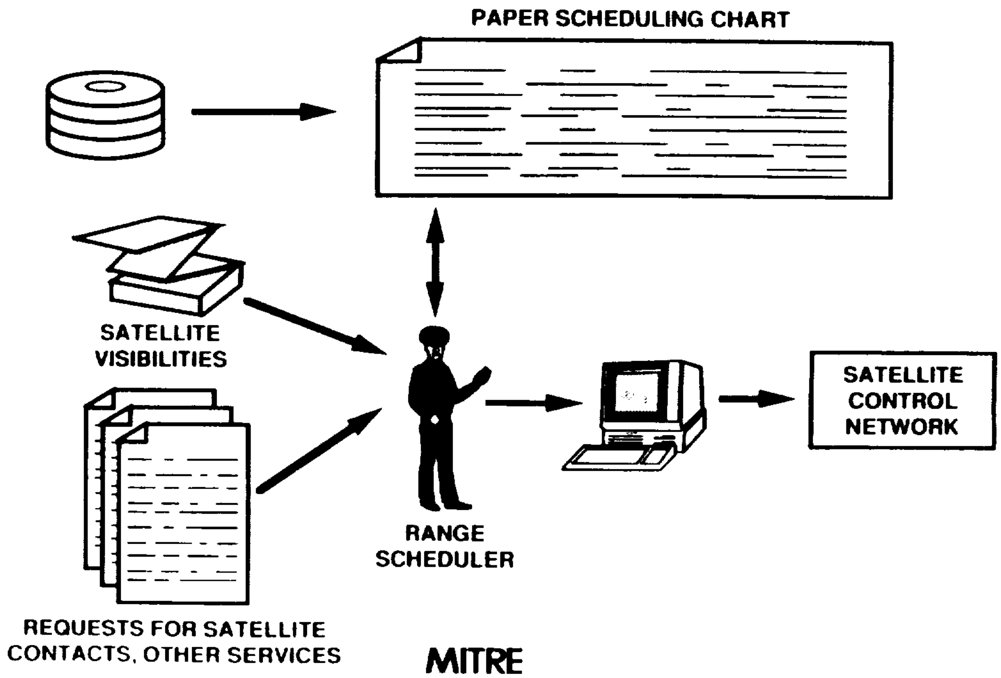
# Range Scheduling - Current Approach




MITRE

S-3

# MITRE Tasking

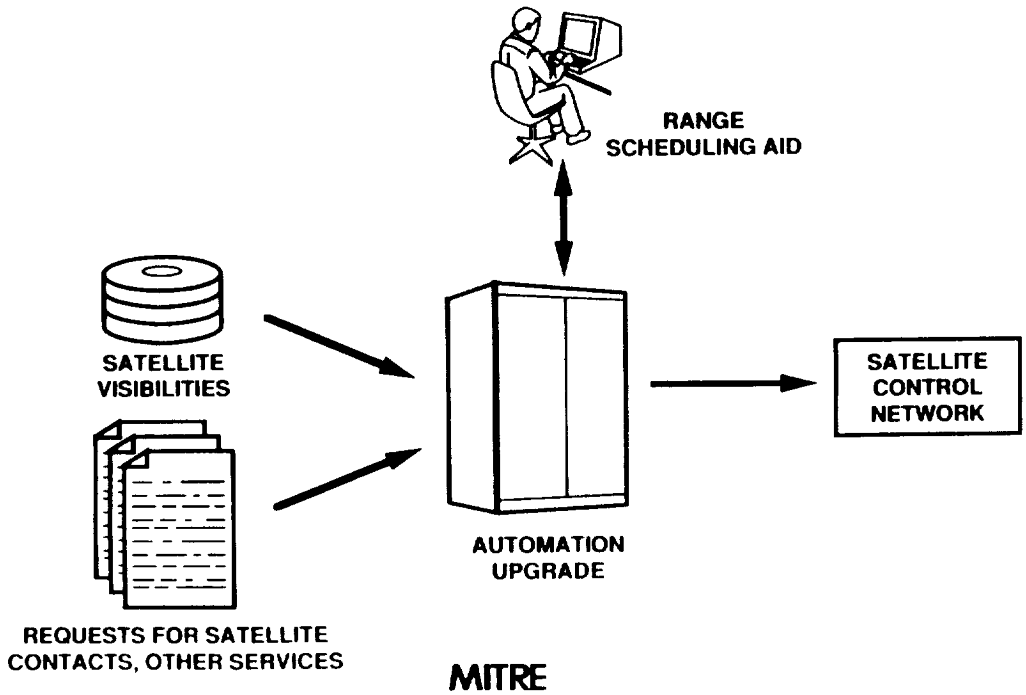
- "Investigate the feasibility and utility of developing a knowledge-based scheduling aid..."
- Approach:
  - Replicate current scheduling in automated environment
  - Develop prototype with user interaction
  - Create user-friendly, graphical interface

MITRE



S-4

# Range Scheduling - New Approach




MITRE

S-5

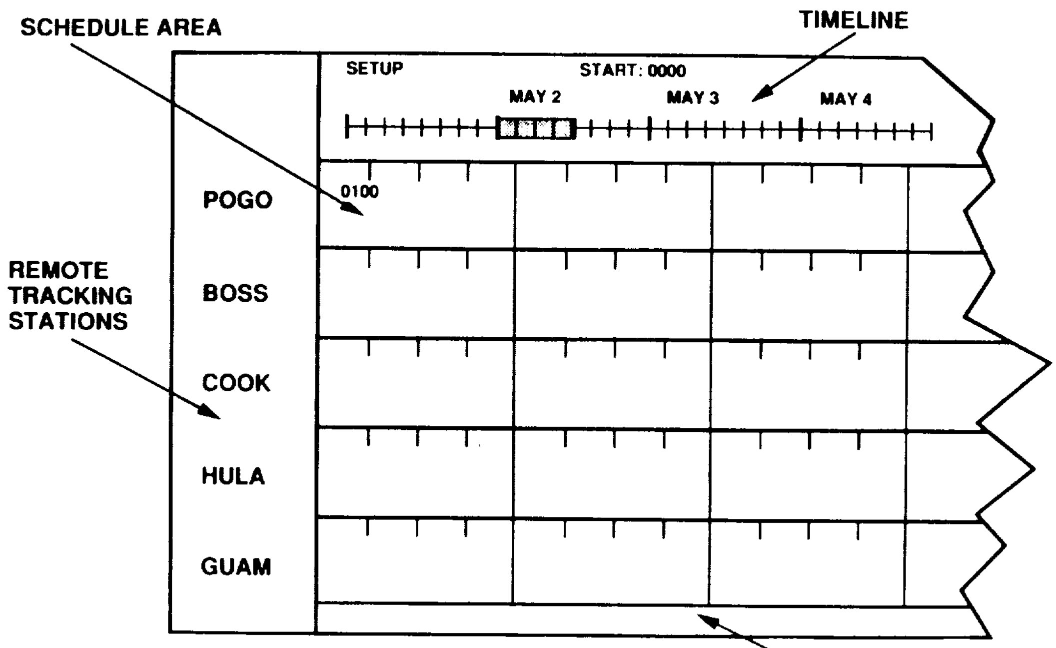
# RSA Features

- Graphical User Interface
  - Similar look and feel to paper based approach
  - Real-time response to schedulers
- Constraint Based Analytical Capability
  - Provides scheduling tools
  - Automates scheduler heuristics
- Multi-user
  - Architecture supports real-time multi-user capability
- Portable
  - Sun, Symbolics, TI Explorer, and Mac II



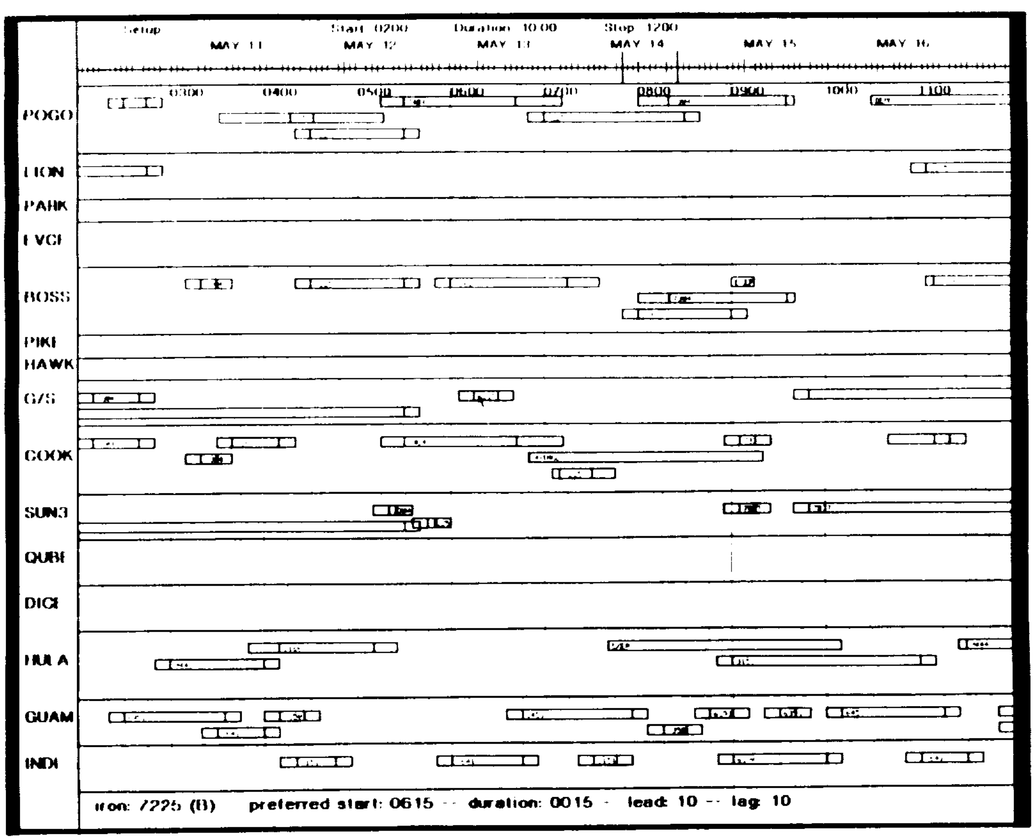
S-6

# Range Scheduling Aid Display



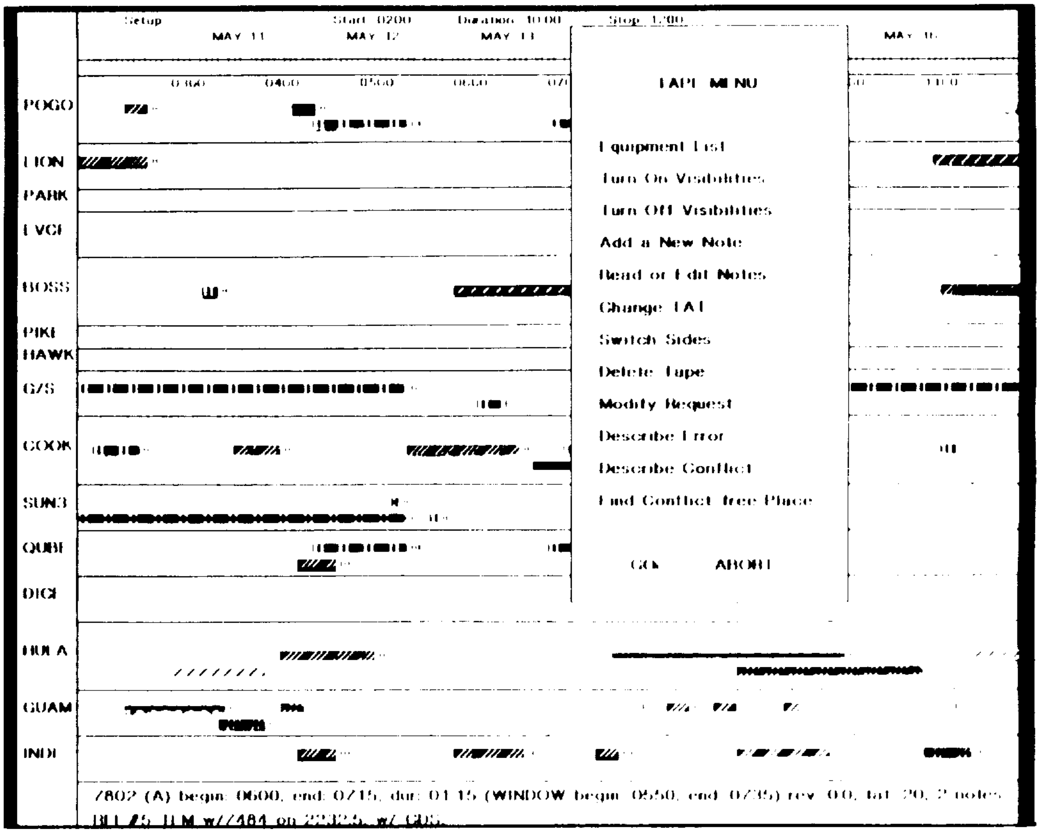

MITRE

S-7






S-8




S-9

# Constraint Based Analytic Capability

- **Conflict Identification**
  - **Oversubscribed resources?**
    - **At local Remote Tracking Station**
    - **Across AFSCN**
  - **Adequate turnaround time**
- **Conflict Explanation**
  - **Type of conflict**
  - **Specific resources and times associated with conflict**

S-10

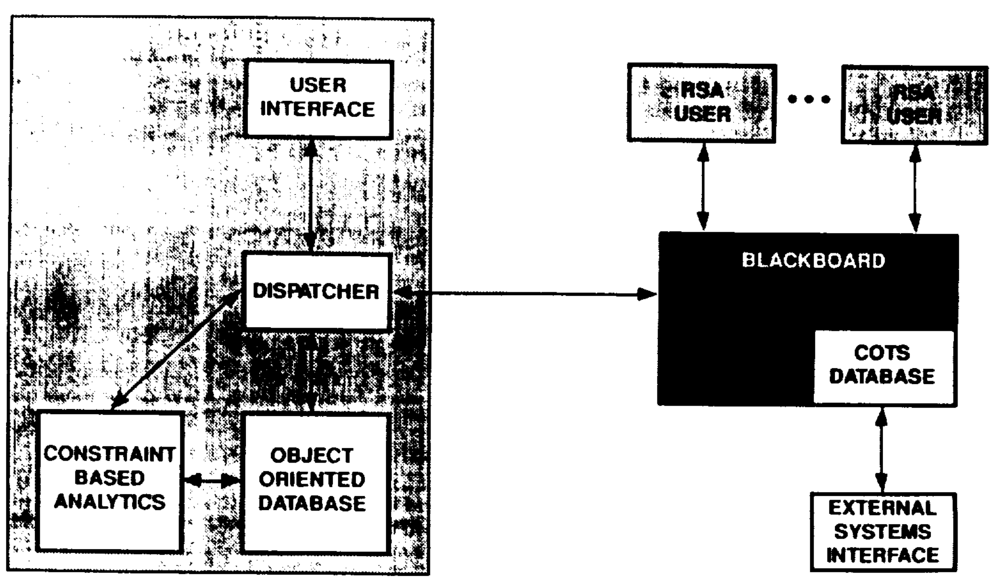
# Constraint Based Analytic Capability (concluded)

- Conflict Resolution
  - For single task (list of possible solutions)
  - Globally across time slice
- Error Checking
  - Satellite visible?
  - In requested time window?
  - At proper RTS?

MITRE

S-11

# RSA Architecture




MITRE

S-12

# Range Scheduling Aid Benefits

- Automated scheduling
- Electronic schedule dissemination
- Simultaneous scheduling
- Extensible system
- Reduced training time

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S-13

N92-11058

# SCHEDULING TECHNIQUES IN THE REQUEST ORIENTED SCHEDULING ENGINE (ROSE)

December 13, 1990

David R. Zoch
Telemail: DZOCH
Phone: 805.0457

LORAL AeroSys

SEAS
Systems, Engineering, and Analysis Support

T-1

## Agenda

- Introduction to ROSE
- NCC-ROSE (test results)
- ROSE Scheduling Approach
- Scheduling Techniques
- Summary

GSFC Contacts for ROSE Projects:

G. Mike Tong (Code 520) ATR for ROSE*Ada
Larry Hull (Code 520)
Nancy Goodman (Code 520) ATR for NCC-ROSE
Sylvia Sheppard (Code 520)

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# ROSE Summary

- *ROSE* is a prototype scheduling tool that has demonstrated viable solutions to difficult scheduling issues such as:
  - Fast, automated, conflict-free schedule creation (> 4,000 request/hour @ 2,000 req's.)
  - Schedule enhancement through post-processing: Best First Search for Schedule Enhancement (BFSSE).
  - Rescheduling / contingency scheduling techniques
  - Operator tools for computer-assisted scheduling (graphical interfaces, etc.)

- The *ROSE* effort involves the cooperation of experienced users, operators, and implementors of spacecraft data systems

- The *ROSE* effort has had positive impacts far beyond its original scope

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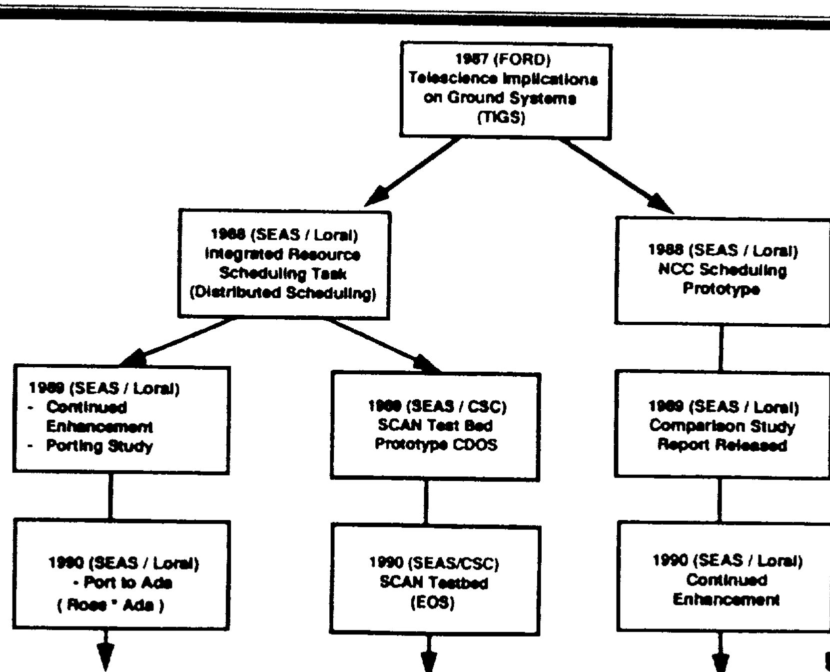
# ROSE History

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## NCC - ROSE Task Goals

- Prototype a viable generic NCC request scheduling process with predicted load levels for the 1995 timeframe using:
  - Existing *ROSE* prototype
  - Different request selection and placement strategies
  - Different scheduling algorithms
- Use requests that represent a realistic contention for TDRSS resources with realistic view periods
- Prototype required user request flexibility
- Evaluate FERN language for use in the NCC environment
- Determine tradeoffs between *success rates* and *time-to-schedule* for different scheduling algorithms

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## Accomplishments

- Verified ability of FERN to represent realistic generic requests by building and scheduling generic requests:
  - 31 Generic user requests
  - 11 Missions
  - Requests for 1645 activities per week
  - Realistic TDRS view periods
  - Realistic resource contention
- Prototyped and compared scheduling architectures
- Results documented in *Scheduling Results Analysis Report for the NCC Prototype*
- Able to schedule over 94% of anticipated requests for week long schedule in 1995 in less than 2 hours

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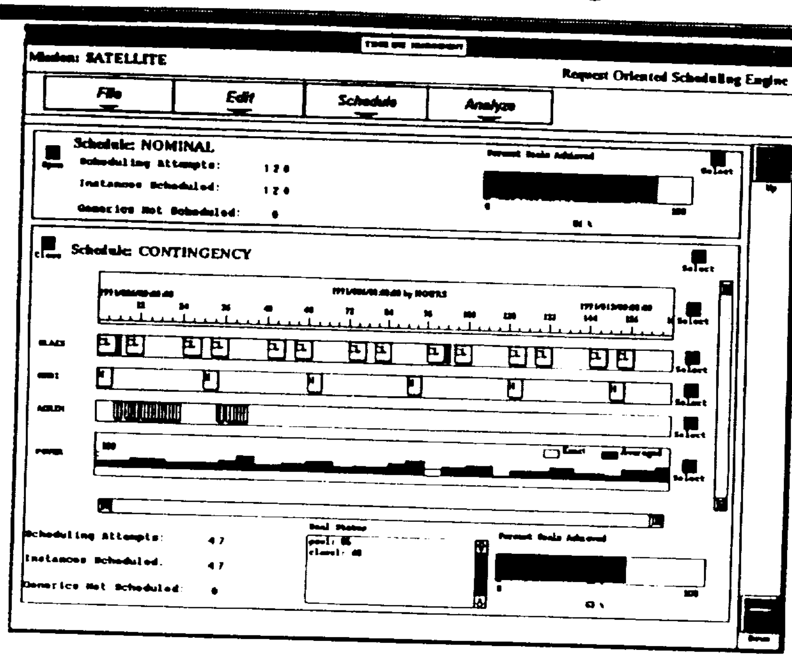
# ROSE Timeline Manager

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# Scheduling Concerns

- Need to reduce time needed to get a conflict-free schedule
- Satisfy customers
- Respond quickly to changes (Targets of opportunity, shuttle slips)
- Implement NASA policy

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T-8

## Current Approach

1 Users submit requests for services at a specific time

2 INITIAL SCHEDULING (2 hours) - An initial schedule is created by computer

3 CONFLICT RESOLUTION (3 to 5 days) - operators phone users and ask
- what is the type of event? (orbit adjust, tape dump, etc.)
- can request be shortened?
- can request be moved?
- can request use a downgraded service (MA vs. SA)
- can request use the other TDRS?
- If neither conflicting user is flexible, choose the higher priority one.

4 Operators schedule PM and tests (hardware/software upgrades) around user requests

5 If there is a conflict with a user, do the conflict resolution process

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## ROSE Approach

1 Users <u>and Operators</u> submit <u>flexible</u> requests with <u>preferences, constraints, and alternatives</u>

2 INITIAL SCHEDULING (1 to 2 hours) - An initial schedule is created (without conflicts). Some requested events are not scheduled

3 CONFLICT RESOLUTION (2 to 5 hours) - Algorithms that imitate the human conflict resolution process are executed to try to schedule the non-scheduled requests

4 (done)

5 (done)

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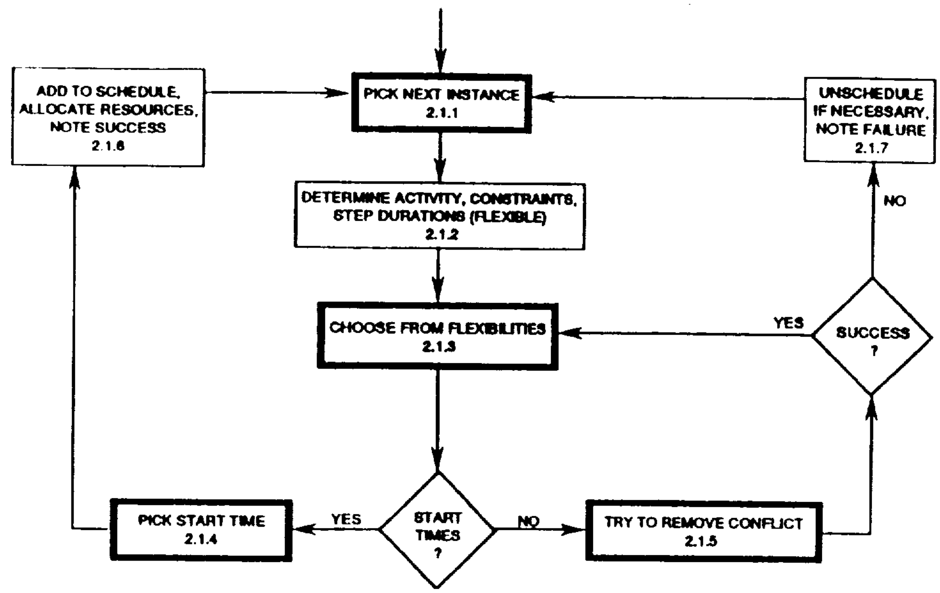
T-10

# Initial Scheduling

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# BFSSE Overview

- Start with an initial conflict-free schedule and some un-scheduled requests
- Identify one un-scheduled request that you would like to try to schedule
- The algorithm executes the following three steps repeatedly as needed until either a solution is found or a timeout occurs
  - SELECT
    Find places on the schedule where the request almost fits.
  - MOVE
    Determine what requests need to be moved to schedule the unscheduled request
  - RESCHEDULE
    Repeat the SELECT and MOVE steps for all moved requests

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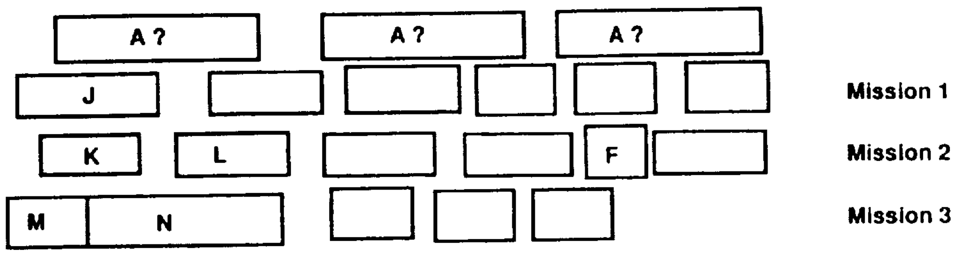
# BFSSE Example

- Goal is to add request "A" to the existing schedule shown below
- Three potential times for request "A" are shown




- It is known that "A" cannot be scheduled anywhere if the rest of the schedule remains as is.

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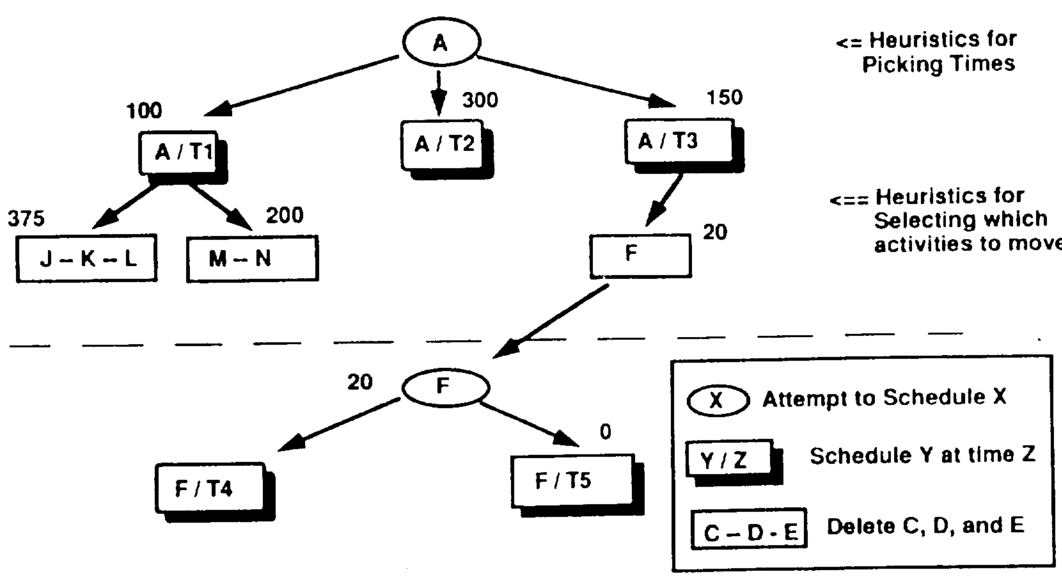
# BFSSE Example (cont'd)

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# Summary

- ROSE has shown to be an effective scheduler for solving the types of scheduling problems faced by the NCC
- The ROSE approach fully supports the NCC operations scenario
- Conflict-free schedules can be created in 2 to 4 hours instead of 3 to 5 days.
- ROSE can create schedules quickly enough that alternative contingency schedules are possible
- The ROSE conflict resolution strategy utilizes flexibilities in user requests to reduce conflicts

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T-15

N92-11059

## Managing Temporal Relations in the MAESTRO Scheduling System*

Daniel L. Britt

Martin Marietta Information Systems Group

303-977-4491

*Based on the paper *Managing Temporal Relations*, coauthored with Amy L. Geoffroy and John R. Gohring, which appears in: "Proceedings of the Goddard Conference on Space Applications of Artificial Intelligence". May, 1990, NASA GSFC, Greenbelt MD.



## INTRODUCTION

Scheduling defined

Why scheduling is hard

Scheduling domains are information-rich

An effective scheduling approach - Use as much information as possible while keeping the computational workload manageable

MAESTRO adhers to this principle via resource opportunity calculation and temporal constraint propagation

How MAESTRO manages temporal relations

## DEFINITIONS

Activity - A sequence of operations, steps or subtasks which, when executed, accomplishes one or more goals. Each activity has associated resource, conditions, state, and timing requirements, all of which must be met for the activity to accomplish its goal(s).

Scheduling - The specification of start and end times for subtasks making up activities, and the specification of resources to be used for each, if there are choices among them.

Viable Schedule - A timeline of activity performances on which all of the performances can successfully be executed, given the truth of the assumptions upon which that schedule was based.

Space Network Control Workshop, Goddard Space Flight Center Dec 12&13, 1990

MARTIN MARIETTA

Managing Temporal Relations in the MAESTRO Scheduling System Dan Britt 2

U-3

## Activity ATMOS - Atmospheric Spectroscopy

Activity Structure

| subtasks | duration min | duration max | delay min | delay max |
|---|---|---|---|---|
| A1 - Power Up | 3 | 3 | n/a | n/a |
| A2 - Self test | 1 | 1 | 0 | 0 |
| A3 - Calibrate | 4 | 6 | 0 | 5 |
| A4 - Repoint | 1 | 10 | 0 | 10 |
| A5 - Collect Data | 18 | 36 | 0 | 10 |
| A6 - Power Down | 3 | 3 | 0 | 0 |

Resource Use

| subtasks \ resources | ATMOS Instrument | Power | Data | Vibration | Sun excl angle | Day/night |
|---|---|---|---|---|---|---|
| A1 - Power Up | X | 100 w | | | | |
| A2 - Self test | X | 100 w | 4 kbps | | | |
| A3 - Calibrate | X | 250 w | 1 kbps | | | |
| A4 - Repoint | X | 400 w | | causes 1000 µg | | |
| A5 - Collect Data | X | 200 w | 2 kbps | < 650 µg | > 32 deg | daylight only |
| A6 - Power Down | X | | | | | |

Temporal Constraint - Subtask A5 must start 2 - 5 minutes after SOLAR subtask S4 starts

Placement Preferences - Frontload, maximizing subtask durations and minimizing delays between subtasks

Space Network Control Workshop, Goddard Space Flight Center Dec 12&13, 1990

MARTIN MARIETTA

Managing Temporal Relations in the MAESTRO Scheduling System Dan Britt 3

U-4

## WHY SCHEDULING IS HARD

1) Desirability - Difficulty in determining when you've got a good schedule, given that different people, agencies, etc. have differing goals and priorities.

2) Stochasticity - Unpredictability in the domain that makes predictive scheduling problematical.

3) Tractability - Computational complexity of the domain, the "size" of the scheduling problem.

4) Decidability - It may be provably impossible to find an algorithm which produces an optimal schedule, depending on the definition of optimality chosen.

H. Van Dyke Parunak - "Why Scheduling Is Hard (And How To Do It Anyway)", *Proceedings of the 1987 Material Handling Focus (Research Forum)*, Georgia Institute of Technology, September 1987.



U-5

## TRACTABILITY

Scheduling - searching a large, many-dimensional problem space, throughout which are scattered viable schedules.

Given 100 activities using any of 100 resources and starting at any of 100 times this space contains aproximately $10^{300,000}$ possible schedules.

Viable schedules make up a tiny percentage of all schedules.

"Good" schedules can constitute a small fraction of all viable schedules.

Optimal schedules can make up a small percentage of all "good" schedules.



U-6

## SCHEDULING DOMAINS ARE INFORMATION-RICH

Activity structure

Activity temporal constraints

Resource types, use functions, availabilities

Preferences in activity placement, resource use, etc.

Schedule evaluation criteria (subjective)

Ways contingencies happen & can be dealt with

Space Network Control Workshop,
Goddard Space Flight Center
Dec 12&13, 1990

MARTIN MARIETTA

Managing Temporal Relations in the
MAESTRO Scheduling System
Dan Britt

6

U-7

### Domain Information Usable By A Scheduler

Some or all of the following is available in a typical scheduling domain. Other information may be available as well.

1) Structure of each activity (number of subtasks, operations or steps)
2) Subtask durations, delays between subtasks for each activity
3) Subtask resource and conditions requirements, choices between resources used
4) Relationships between subtask durations & resource use
5) Relationships between conditions availabilities and subtask durations
6) Effects of subtask execution on resource, condition and state availabilities
7) Time windows in which subtasks can be scheduled
8) Required temporal relations between subtasks, in an activity or between two or more activities
9) Temporal relations between subtasks and events or times
10) Alternative ways to satisfy temporal constraints
11) Alternate descriptions of activities
12) Resource and conditions availabilities
13) States of schedule-relevant objects
14) Interactions between resources
15) Position on timeline of events and already-scheduled activities
16) User preferences in activity or subtask placement
17) Preferences in subtask resource use
18) Preferences in ways to satisfy temporal constraints
19) Priority of each activity
20) Number of times each activity should be scheduled
21) Time period being scheduled over
22) Average frequencies of various failures
23) Typical times for repair& maintenance
24) Ways to continue an interrupted activity
25) Time available to create a schedule
26) Time available to modify a schedule being executed
27) Importance of minimally satisfying lots of requests vs that of "near-optimally" satisfying a few requests
28) Importance of getting on high-priority activity done vs getting several lower-priority ones done



U-8

The preceding information can be used to generate other potentially useful information:

29) Summed activity resource requirements
30) Ways two or more activities can fit together or will conflict
31) Time windows during which all resource requirements for a subtask are satisfiable.
32) Time windows from which to choose subtask starts and ends such that the whole activity can be placed
33) Percent resource use, percentage of activity requests satisfied, and other schedule evaluation metrics

In most scheduling domains an important piece of information cannot be determined - why an activity cannot be scheduled. It may be possible to list all the reasons why an activity cannot be scheduled at a particular time, with fixed durations for its subtasks and fixed delays between them, but this information cannot efficiently be determined for activities which allow variability in placement. Also, some of the information listed earlier will be subjectively determined, and these determinations can vary over time and between people, though this will not necessarily make this kind of information unuseful.

U-9

## AN APPROACH TO SCHEDULING

Represent all available domain information to scheduling system

Perform computations which analyze input info and synthesize other info while not incurring unacceptable overhead

Use domain info and synthesized info to incrementally make decisions which remove "bad" schedules from the search space while keeping "good" ones

Do not allow representable constraint violations, ruling out the vast majority of the search space implicitly



U-10

## THE MAESTRO SCHEDULING SYSTEM

Opportunity Calculation finds all places on a current partial schedule wherein each subtask can be executing w/resp to resources, conditions, states and time windows

Temporal Constraint Propagation uses this & other constraint info to specify time windows from which subtask starts and ends can be chosen such that a whole activity can be placed

An activity is selected to be scheduled using these results and user-specified criteria indicating importance of various heuristics

Selected activity is placed on the schedule using results of constraint propagation and placement preference info

User can select activity to schedule and/or can place selected activity using results of above computations



## MANAGING TEMPORAL RELATIONS

A. Constraints on the Placement of a Single Activity

B. Constraints Between Activities

C. Soft Constraints

D. Contingency Handling

## CONSTRAINTS ON THE PLACEMENT OF A SINGLE ACTIVITY

A. Resources and conditions

B. Time windows

C. Activity structure

1. durations and delays, with variability
2. nonadjacent subtask relations, activity duration



## CONSTRAINTS BETWEEN ACTIVITIES

A. Precedes, follows, starts, ends, and conflicts, with variable offsets

B. One-way versus two-way constraints

C. Constraint arities

D. Relations to events and to absolute times

## Soft Constraints

A. General preferences

1. loading
2. durations and delays

B. Specific preferences

1. maximize one duration
2. place subtask near to or far from a subtask, event or time

C. Random placement

D. User placement



## CONTINGENCY HANDLING

A. Schedule late-arriving request

B. Unschedule (bump) to fit new request

C. Unschedule to reflect resource availability changes

D. Interrupt and restructure an activity in real time

# Resource Representation in COMPASS*

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Houston, Texas 77062
(713) 488-7410

*Research support in part by code MD & MT

V-1

1

Outline

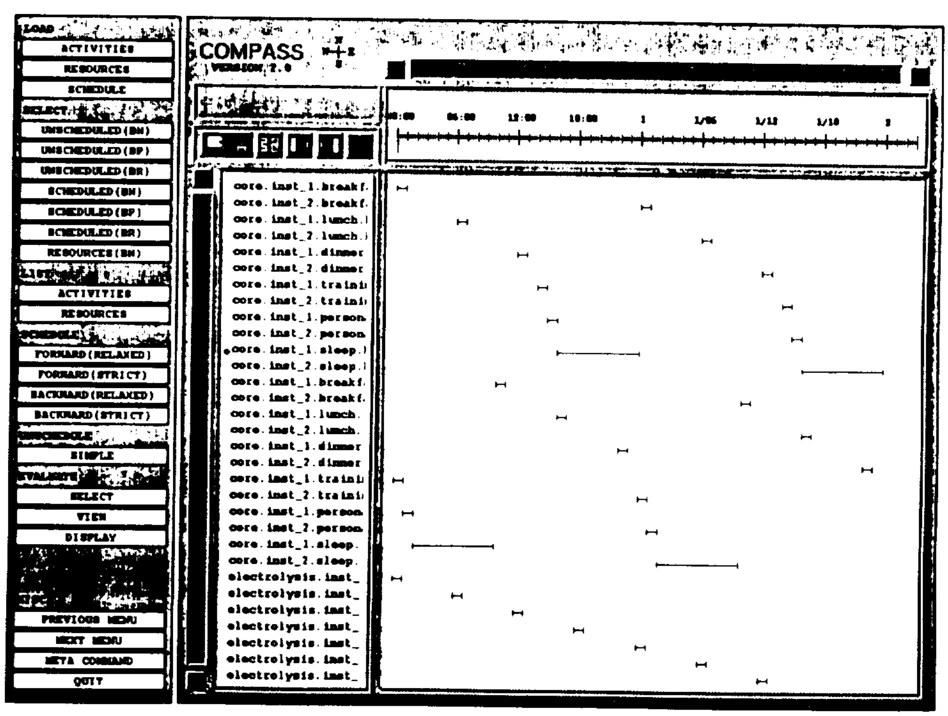
- Introduction
- Statement of the Problem
- Representation of Resource Requirements
- Representation of Resource Availability
- Algorithm for Activity Placement
- Conclusion

V-2

# Introduction

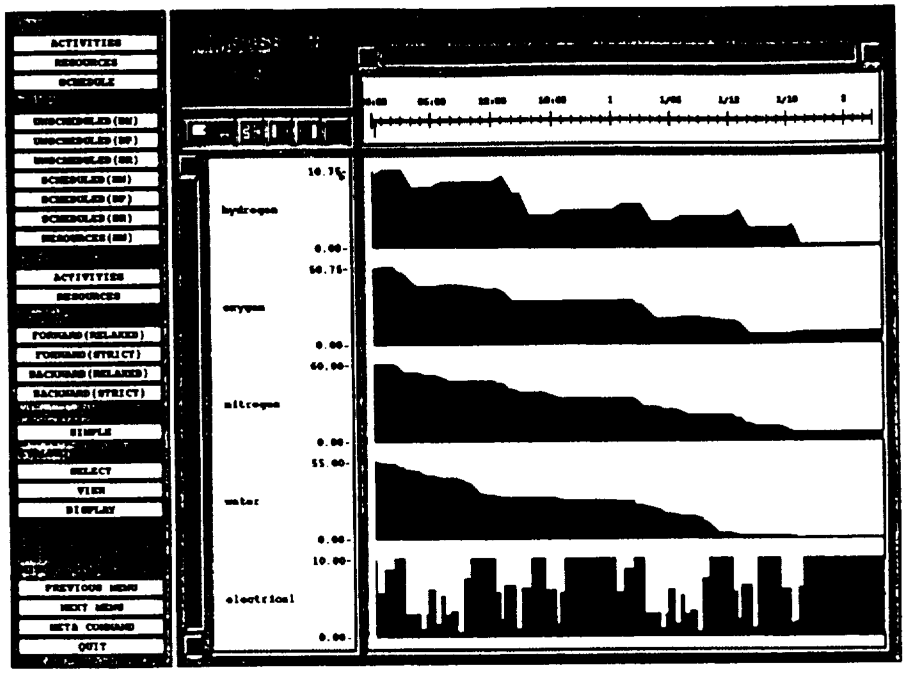
COMPASS is an incremental, interactive, non-chronological scheduler written in Ada with an X-Windows user interface.

V-3






V-4




V-5

3

## Introduction

### Incremental

beginning with an empty schedule, activities are added to the schedule one at a time, taking into consideration the placement of the activities already on the timeline and the resources that have been reserved for them.

### Interactive

the order that activities are added to the timeline and their location on the timeline are controlled by selection and placement commands invoked by the user.

### Non-Chronological

the order that activities are added to the timeline and their location are independent

V-6

## Introduction

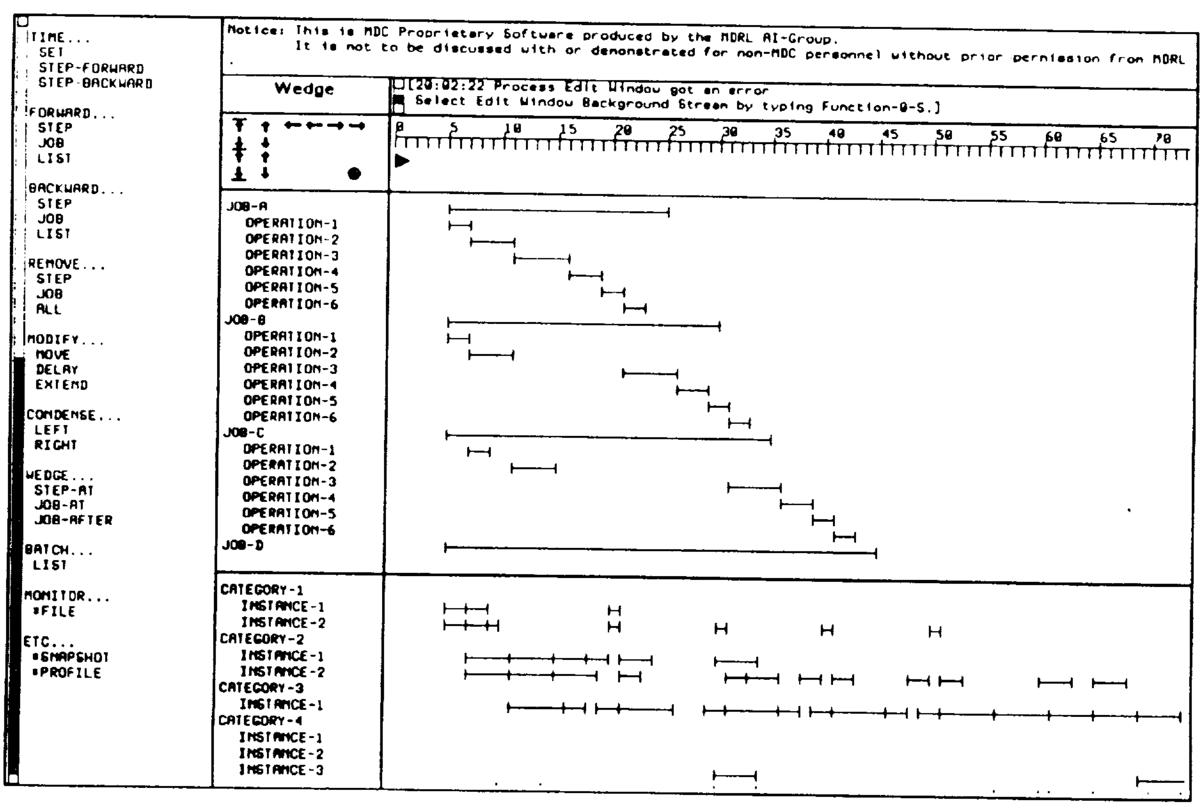
COMPASS is the successor of Wedge (1986), a scheduler of similar capability written in Lisp on a Symbolics machine.

COMPASS contains portable, generic packages that were useful and necessary in the conversion of a major Lisp program to Ada

- Lookahead I/O
- Stream Oriented I/O
- Symbol Data Types
- Generic List Package

COMPASS can be useful to anyone planning the conversion of software that relies heavily upon lists and symbol data types.

V-7




V-8

4

## Statement of the Problem

An activity can be performed only if all of its required resources are available in sufficient quantity for a sufficient duration of time.

A schedule must arrange activities so that the combined resource requirements at any point in time do not exceed the resource availability.

V-9

5

## Statement of the Problem

Implementation of interactive and automated scheduling systems requires

an external (textual) representation for resource requirements,
an internal representation for resource requirements,

an external (textual) representation for resource availability,
an internal representation for resource availability,

an algorithm for placing activities on the timeline so that the combined resource requirements at any point in time do not exceed the resource availability.

V-10

## Statement of the Problem

6

NASA requires access to advanced scheduling technology.

Basic scheduling data structures and algorithms should be publicly available "textbook" knowledge.

- This enables traditional "time and space" analysis of proposed methods.
- This enables objective comparison of methods, unobscured by differences in implementation languages and hardware.
- This enables the creation of new scheduling applications without the costly process of re-discovery and re-invention.

V-11

## Representation of Resource Requirements

7

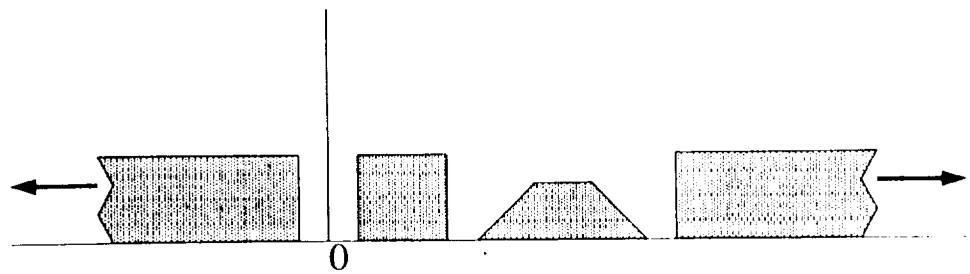
Resource requirements can be classified by the properties of the function that defines the quantity required at each point in time.

- Location of the origin
- Shape and continuity
- Sign
- Extent

V-12

## Representation of Resource Requirements

COMPASS represents resource requirements by piecewise linear functions.




The origin is relative to the beginning of the activity.

Positive quantities represent the amount required by an activity.

Positive segments with finite extent represent assignment.

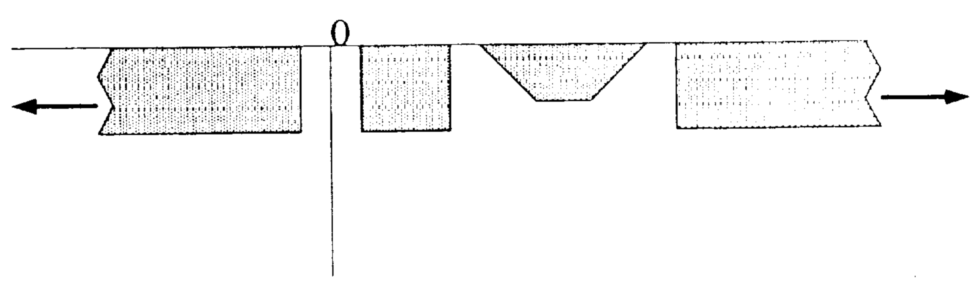
Positive segments with infinite extent represent consumption.

V-13



## Representation of Resource Requirements

COMPASS represents resource requirements by piecewise linear functions.




The origin is relative to the beginning of the activity.

Negative quantities represent the amount provided by an activity.

Negative segments with finite extent represent ____________ .

Negative segments with infinite extent represent production.

V-14

9a

## Representation of Resource Requirements

This representation is suitable for a wide variety of resources including:

electrical, thermal, communications, etc.
water, oxygen, hydrogen, nitrogen, etc.
crew members
screwdrivers, hammers, pliers, etc.
replaceable parts, packaged food, disposable clothing,etc.
storage capacity
mass and volume

V-15

9b

## Representation of Resource Requirements

COMPASS provides a dotted notation for resource names which enables "wildcard" resource requirements.

Given four crew members named: crew.so.bob
crew.so.carol
crew.ss.ted
crew.ss.alice

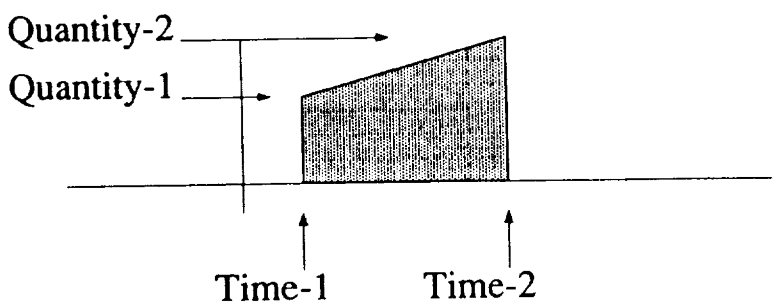
| request | crew.ss.ted | crew.so | crew |
|---|---|---|---|
| instances | crew.ss.ted | crew.so.bob<br>crew.so.carol | crew.so.bob<br>crew.so.carol<br>crew.ss.ted<br>crew.ss.alice |

V-16

10

## Representation of Resource Requirements

Piecewise linear functions are represented as an ordered list of segment descriptors:

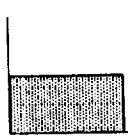



( Quantity-1 Quantity-2 ) / [ Time-1 Time-2 ]

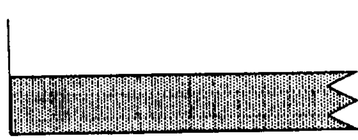
V-17

11

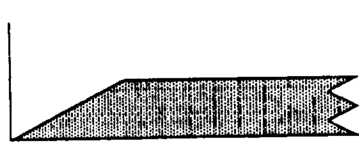
## Representation of Resource Requirements



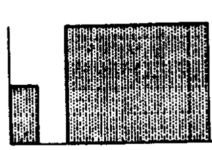
(1.0)/[0 1:00] ;



(1.0)/[0 +inf] ;



(0.0 1.0)/[0 1:00] (1.0)/[1:00 +inf] ;



(1.0)/[0 0:15] (2.0)/[0:30 1:45] ;

V-18

Representation of Resource Requirements 12

Notation for time:

| | |
|---|---|
| 1 | 1 day |
| 1/2 | 1 day, 2 hours |
| 1/2:03 | 1 day, 2 hours, 3 minutes |
| 1/2:03:04 | 1 day, 2 hours, 3 minutes, 4 seconds |
| 2:03 | 2 hours, 3 minutes |
| 2:03:04 | 2 hours, 3 minutes, 4 seconds |
| 12/31/1990 | December 31, 1990 |
| 12/31/1990 @ 2 | December 31, 1990 at 2:00 |
| 12/31/1990 @ 2:03 | December 31, 1990 at 2:03 |
| 12/31/1990 @ 2:03:04 | December 31, 1990 at 2:03:04 |

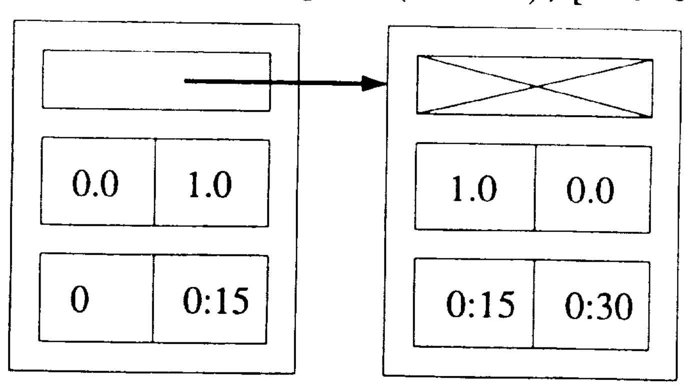
(32 bit internal representation: +/- 65 years at resolution of 1 second)

V-19

Representation of Resource Requirements 13

Piecewise linear functions are represented by linked lists of <ramp>/<interval> pairs created using the generic list package.

(0.0 1.0) / [0 0:15] (1.0 0.0) / [0:15 0:30] ;




Total memory required is proportional to the amount of detail, not to the span of time!

V-20

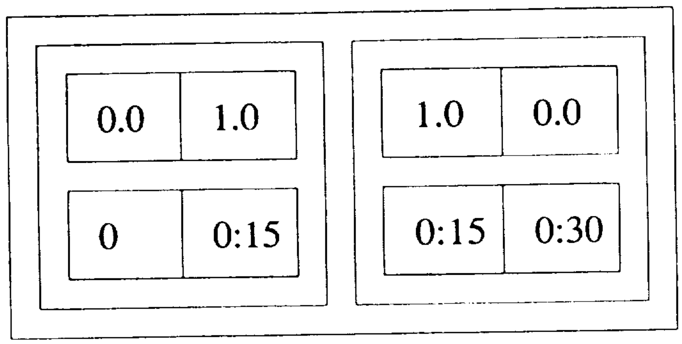
13a

## Representation of Resource Requirements

Given Ada's ability to create dynamically sized arrays,
it is feasible to represent lists as both linked lists and arrays!

However, this is safe only if the compiler correctly implements unchecked deallocation!

(0.0 1.0) / [0 0:15] (1.0 0.0) / [0:15 0:30] ;




V-21

14

## Representation of Resource Availability

COMPASS represents resource availability by piecewise linear functions.

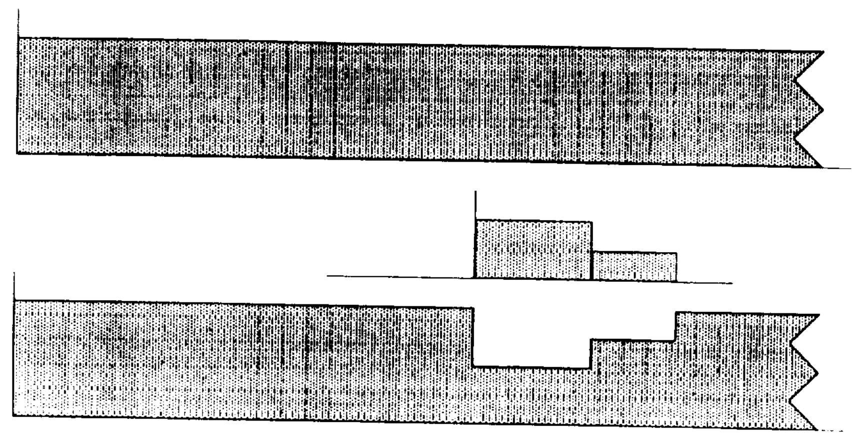
V-22

## Algorithm for Activity Placement

15

To schedule an activity

- locate a time where its resource requirement can be satisfied
- schedule the activity to occur at that time
- translate its resource requirement to that time
- subtract its resource requirement from the resource availability



V-23

## Algorithm for Activity Placement

16

Subtraction of the resource requirement from the resource availability ensures that the resource requirement will be satisfied even after other activities are added to the timeline.

Subsequently, another activity can be scheduled to occur at the same time only if its resource requirement can be satisfied by the remainder.

The reversibility of this method for resource reservation enables us to "unschedule" an activity by adding its resource requirement back into the resource availability!

V-24

## Algorithm for Activity Placement

To locate where a resource requirement can be satisfied

- locate where each segment of the requirement can be satisfied
- normalize the results and combine by interval intersection

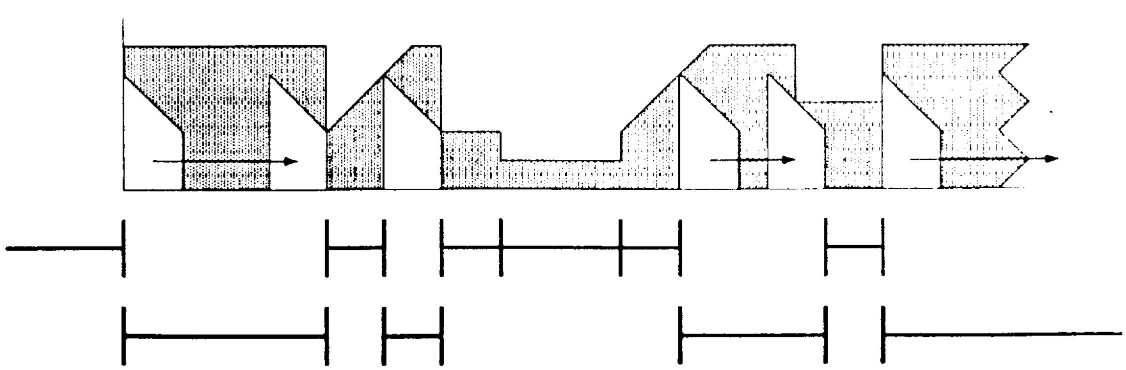
V-25



## Algorithm for Activity Placement

To locate where a segment of a requirement can be satisfied

- Begin by assuming that all of time is satisfactory
- Consider each segment of the resource availability
  - If there is a subsegment which is not satisfactory then exclude it from the answer.



V-26

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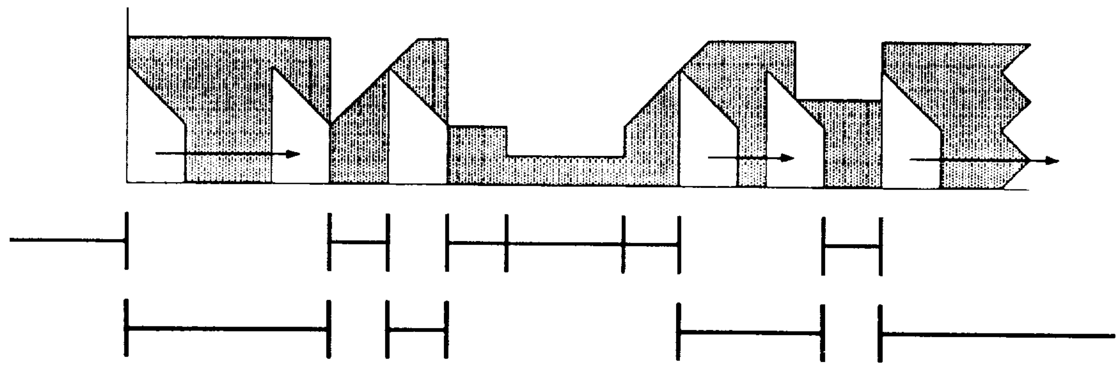
## Work in Process

This same algorithm for computing feasible intervals of time can be used for pattern matching against other numeric data, like latitude, longitude, light and dark, which can be reasonably approximated by piecewise linear functions. (Special notation needs to be introduced in order to represent conjunction and disjunction.)



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## Work in Process

Few resources can be accurately modeled as quantity available over time.

Rather than building more complex, domain specific models into COMPASS, we are building a distributed system of schedulers and resource managers that communicate with each other through a stylized protocol of requests and reservations.

Interprocess communication is greatly facilitated by the stream oriented I/O facilities already part of COMPASS.

Development of the basic capabilities is being performed jointly with the COOPES project. Specific resource models are being developed under the MDC IR&D program.

V-28

## Full Activity Representation

```
Activity
Name                          Crystal.Step_2
Priority                      10
Value                         5000
Penalty                       1000
Predecesor_List               (Crystal.Step_1)
Successor_list                ()
Non_ConCurrent_Activity_List  ()
Temporal_Constraint_List      [Start of * <= Finish of Crystal.Step_1 + 0:15] ;
Duration                      1:15
Earliest_Start                3/00:00
Latest_Finish                 3/12:00
Preferred_Interval_list       [3/04:00 3/05:30] [3/07:00 3/08:30] ;
Required_Resources            Crew          (1.0)/[0 1:15] ;
                              Electricity   (5.5)/[0 0:15] ( 9.0)/[0:15 1:15] ;
                              Thermal       (5.5)/[0 0:15] (14.0)/[0:15 1:15] ; ;
Required_Conditions           MicroGravity      T/[0:15 1:00] ; ;
Activity_End
```

V-29



## Conclusion

The COMPASS code library is a cost-effective platform for the development of new artificial intelligence applications that must be delivered in Ada and X-Windows.

It implements symbols, strongly typed lists, and stream oriented low-level i/o libraries which are based upon very simple requirements and pragmatic compromises.

The implementation has been tested in the context of a large complex, computationally intensive application.

The implementation is being refined on the basis of design reviews, code audits, time and space benchmarks, and the wisdom of hindsight.

V-30

## Conclusion

The COMPASS code library is a cost-effective platform for the developement of new scheduling applications.

The code library contains generic, portable, modular, and adaptable scheduling technology.

It can be effectively used off-the-shelf for compatibile scheduling applications or it can be used as a parts library for the development of custom scheduling systems

It has proved useful as a neutral benchmark for comparing the time, space, and qualitative performance of existing schedulers.

It has proved useful for assessing the feasibility of building scheduling systems, and other symbolic applications in Ada.

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# Appendix B—List of Attendees

SNC Conference on Resource Allocation - List of Attendees

| Name | Organization | Street Address | City, State, Zip Code | Telephone |
|---|---|---|---|---|
| David W. Harris | NASA HQ, Code OX | | Washington, DC 20546 | 202/454-2030 |
| Ed Lowe | NASA HQ, Code OX | | Washington, DC 20546 | 202/454-2058 |
| Rhoda S. Hornstein | NASA HQ, Code OX | | Washington, DC 20546 | 202/454-2030 |
| | | | | |
| Angie Kelly | NASA GSFC, Code 423 | | Greenbelt, MD 20771 | 301/286-7726 |
| | | | | |
| Bill Macoughtry | NASA GSFC, Code 501 | | Greenbelt, MD 20771 | 301/286-7155 |
| | | | | |
| Dolly Perkins | NASA GSFC, Code 510 | | Greenbelt, MD 20771 | 301/286-6228 |
| Les Wentz | NASA GSFC, Code 510.1 | | Greenbelt, MD 20771 | 301/286-5563 |
| Arthur Hughes | NASA GSFC, Code 510.1 | | Greenbelt, MD 20771 | 301/286-7311 |
| | | | | |
| Beth Antonopulos | NASA GSFC, Code 511.2 | | Greenbelt, MD 20771 | 301/286-3251 |
| | | | | |
| Wayne Gustafson | NASA GSFC, Code 513 | | Greenbelt, MD 20771 | 301/286-3173 |
| | | | | |
| Patricia Lightfoot | NASA GSFC, Code 514 | | Greenbelt, MD 20771 | 301/286-7378 |
| Tom Barlett | NASA GSFC, Code 514 | | Greenbelt, MD 20771 | 301/286-5579 |
| Carolyn Dent | NASA GSFC, Code 514 | | Greenbelt, MD 20771 | 301/286-3030 |
| | | | | |
| Pepper Hartley | NASA GSFC, Code 522 | | Greenbelt, MD 20771 | 301/286-6887 |
| Karen Moe | NASA GSFC, Code 522 | | Greenbelt, MD 20771 | 301/286-5998 |
| Sylvia Sheppard | NASA GSFC, Code 522.1 | | Greenbelt, MD 20771 | 301/286-5049 |
| Mike Tong | NASA GSFC, Code 522.1 | | Greenbelt, MD 20771 | 301/286-3176 |
| Eric Richmond | NASA GSFC, Code 522.1 | | Greenbelt, MD 20771 | 301/286-2617 |
| Larry Hull | NASA GSFC, Code 522.2 | | Greenbelt, MD 20771 | 301/286-3009 |
| Nancy Goodman | NASA GSFC, Code 522.2 | | Greenbelt, MD 20771 | 301/286-6635 |

## SNC Conference on Resource Allocation - List of Attendees

| Name | Organization | Street Address | City, State, Zip Code | Telephone |
|---|---|---|---|---|
| Bill Watson | NASA GSFC, Code 530 | | Greenbelt, MD 20771 | 301/286-2920 |
| Phil Liebrecht | NASA GSFC, Code 530 | | Greenbelt, MD 20771 | 301/286-7028 |
| Tony Maione | NASA GSFC, Code 530 | | Greenbelt, MD 20771 | 301/286-5943 |
| Candace Carlisle | NASA GSFC, Code 530 | | Greenbelt, MD 20771 | 301/286-9469 |
| Virg True | NASA GSFC, Code 530 | NGT P.O. Drawer GSFC | Las Cruces, NM 88004 | 505/523-1497 |
| Ray Davis | NASA GSFC, Code 530.3 | | Greenbelt, MD 20771 | 301/286-3264 |
| | | | | |
| James Rash | NASA GSFC, Code 531.1 | | Greenbelt, MD 20771 | 301/286-3595 |
| | | | | |
| Keiji Tasaki | NASA GSFC, Code 532 | | Greenbelt, MD 20771 | 301/286-8871 |
| Al Goodson | NASA GSFC, Code 532 | | Greenbelt, MD 20771 | 301/286-7364 |
| | | | | |
| Mark Stokrp | NASA GSFC, Code 534 | | Greenbelt, MD 20771 | 301/286-8422 |
| B.J. Hayden | NASA GSFC, Code 534 | | Greenbelt, MD 20771 | 301/286-3702 |
| Ray Granata | NASA GSFC, Code 534 | | Greenbelt, MD 20771 | 301/286-7037 |
| Greg Blaney | NASA GSFC, Code 534.1 | | Greenbelt, MD 20771 | 301/286-1818 |
| Vern Hall | NASA GSFC, Code 534.1 | | Greenbelt, MD 20771 | 301/286-7920 |
| Allen Levine | NASA GSFC, Code 534.2 | | Greenbelt, MD 20771 | 301/286-9436 |
| Gene Young | NASA GSFC, Code 534.2 | | Greenbelt, MD 20771 | 301/286-6591 |
| | | | | |
| Lynne Cooper | NASA JPL, MS 301-490 | 4800 Oak Grove Drive | Pasadena, CA 91109 | 818/354-3252 |
| David Werntz | NASA JPL, MS 601-237 | 4800 Oak Grove Drive | Pasadena, CA 91109 | 818/354-1270 |
| Norman Reilly | NASA JPL, MS 601-237 | 4800 Oak Grove Drive | Pasadena, CA 91109 | 818/354-1239 |
| | | | | |
| Robert Aller | Aller Associates | 7714 Glenmore Spring Way | Bethesda, MD 20817 | 301/469-8796 |

## SNC Conference on Resource Allocation - List of Attendees

| Name | Organization | Street Address | City, State, Zip Code | Telephone |
|---|---|---|---|---|
| Cathy Bazel | Bendix BFEC/534 | 10210 Greenbelt Rd. #450 | Seabrook, MD 20706 | 301/794-3221 |
| Wen Yen | Bendix BFEC/514 | 10210 Greenbelt Rd. | Seabrook, MD 20706 | 301/794-3134 |
| Brenda Page | Bendix BFEC | 10210 Greenbelt Rd. #500 | Seabrook, MD 20706 | 301/794-3170 |
| Andy Kispert | Bendix BFEC | 10210 Greenbelt Rd. | Seabrook, MD 20706 | 301/794-3128 |
| Dave Miller | COMSO, Inc. | 7701 Greenbelt Rd. | Seabrook, MD 20706 | 301/622-0060 |
| Fred Messing | CSC | 4600 Powder Mill Rd. | Beltsville, MD 20705 | 301/572-8234 |
| Surender Reddy | CSC/520 | 4600 Powder Mill Rd. | Beltsville, MD 20705 | 301/572-8311 |
| Todd Welden | CSC/520 | 4600 Powder Mill Rd. | Beltsville, MD 20705 | 301/572-8457 |
| Brian Dealy | CSC/520 | 4600 Powder Mill Rd. | Beltsville, MD 20705 | 301/572-8267 |
| Toni Robinson | CTA Inc. | 6116 Executive Blvd. #800 | Rockville, MD 20852 | 301/816-1342 |
| Betty Murphy | CTA Inc. | 6116 Executive Blvd. #800 | Rockville, MD 20852 | 301/816-1262 |
| John A. Gingrich | GE | P.O. Box 8048 | Philadelphia, PA 19101 | 215/354-2439 |
| Arthur S. Paul | Howard University | 2300 6th Street, N.W. | Washington, DC 20059 | 202/806-6661 |
| J. W. Browning | Hughes | 16800 E. Centretech Pkwy. | Aurora, CO 80011 | 303/344-6010 |
| A. Sandor Hasznos | Hughes | 16800 E. Centretech Pkwy. | Aurora, CO 80011 | 303/344-6272 |
| John Willoughby | Information Sciences, Inc. | 304 Inverness Way, #265 | Englewood, CO 80112 | 303/790-0510 |
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# Appendix C—Submitted Papers

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# AUTOMATING THE CONFLICT RESOLUTION PROCESS

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## INTRODUCTION

Schedule conflicts occur when the demand for a resource exceeds the availability of that resource. When a conflict occurs in a constraint relaxation domain, such as the Space Network (SN), an action must be taken to resolve the conflict. Providing alternative times, alternative resources, or a combination of the two, are methods of resolving a conflict. These alternatives are then submitted to the requestor. If no alternative is acceptable, the request will be declined. This process is called conflict resolution.

The purpose of this paper is to initiate a discussion of how the conflict resolution process at the Network Control Center can be made more efficient. The paper will describe how resource conflicts are currently resolved, describe impacts of automating conflict resolution in the ATDRSS era, present a variety of conflict resolution strategies, and suggest discussion topics related to automated conflict resolution.

## CURRENT SPACE NETWORK CONFLICT RESOLUTION

User POCCs transmit Schedule Add Requests (SARs) to the NCC by the beginning of the forecast period week. The forecast period begins fourteen days prior to the week in which services are to be provided. Requests are ordered and placed on the schedule one by one until a conflict occurs. The request causing the conflict is placed in the declined queue. When all requests have either been scheduled or declined, conflict negotiation begins serially, starting with the highest priority rejected request. Current conflict negotiation is a verbal, time consuming process between the Forecast Analyst and the representatives of the user POCCs. Because of security requirements, the user POCCs are not given access to the entire schedule, so they cannot identify their own time and resource alternatives. Because of current system limitations, the Forecast Analyst has little automated information on user POCC requirements, scheduling aids, or Field of View, so it is difficult for the analyst to determine, other than through operational experience, which of the available alternatives will meet the needs of the user.

Current NCC scheduling software, as with many scheduling systems, emphasizes conflict avoidance, rather than conflict resolution. Care is taken to place an event on the schedule in such a way as to avoid potential conflicts. Some of these algorithms include placing the event within tolerance where it will leave the largest gap of remaining unscheduled time, or a look-ahead metric which places the event to avoid conflict with remaining unscheduled events. The problem with this approach is that it looks at the puzzle instead of looking at the piece. In other words, there is no intelligence or knowledge of the applicability or preference of individual user conflict resolution strategies for each of the requests being placed on the schedule. Rather, the focus of scheduling is on the resources, keeping blocks of resource available time open for subsequent requests.

Another difficulty with the current scheduling and conflict resolution process is that current SN service requests do not contain or utilize flexibility. Flexibility can be expressed in a request two ways. A request can include flexibility of start time by specifying a plus or minus tolerance. A request can include flexibility of resource selection by specifying a configuration code which indicates "open selection" for antenna and interface channel. Because of limitations in the scheduling message formats, the NCC software and the POCC scheduling software have caused users not to include time tolerance in their requests. Other network elements requirements have dictated that users specifically request certain resources instead of allowing the NCC to openly select them to avoid conflicts.

In a typical schedule week, in which approximately 480 unclassified event requests were received by the NCC, about twenty percent of these requests resulted in schedule conflicts. Of that twenty percent, around sixty percent were resolved by alternate links, ten percent by slipping the start time, twenty percent by both slipping time and selecting an alternate link, and ten percent were deleted. The fact that ninety percent of the conflicts were resolvable indicates that there is flexibility in the user's requirements which is not expressed in the request to the NCC.

## SN CONFLICT RESOLUTION IN THE ATDRSS ERA

Because the number of service requests and ATDRSS users in the ATDRSS era (1997-2012) will increase three to ten fold, the number of resource conflicts will exceed the current ability to manually resolve them. If conflict resolution is performed one request at a time in priority order, the time required to resolve conflicts will be unacceptable. Automating the process will enable scheduling to be done in a more realistic time frame. To perform automated conflict resolution, information on how to resolve conflicts must be available. It can be identified by the user POCC in each specific service request, and/or be embedded in the knowledge of the NCC scheduling system.

### Embedding the Knowledge

To perform automated conflict resolution, knowledge of user capabilities, user preferences, and SN resources could be embedded in the scheduling system. User capability data includes ATDRS to USAT and USAT to ATDRS field of view information, sun interference data, antenna patterns, and restrictions such as power availability that would limit antenna substitution. Knowledge about user preferences include mission characteristics affecting both flexibility in request parameters, service alternatives, and a weighted priority scheme for relaxing scheduling constraints. Knowledge of the SN includes resource availability, resource capability, RFI, to include antenna pattern overlap of scheduled USATs, and antenna slew time.

Using the above knowledge, a conflict resolution profile could be created by the NCC for each user POCC service request defining a hierarchy of conflict resolution strategies applicable in each instance to the particular user spacecraft, service parameter tolerances, and dependencies between spacecraft services. The hierarchy would indicate the **types** of strategies to be used to resolve conflicts and the **order** in which they should be used.

The knowledge about the specific user conflict resolution preferences could be input to the NCC scheduling system by the user POCC during service planning similar to a generic scheduling concept, elicited from scheduling experts at the NCC, and/or learned by the system during analyst-in-the-loop conflict negotiation.

### User Specifying the Knowledge

An alternative to embedding all the knowledge in the NCC scheduling system is to include the information affecting conflict resolution strategies in the service request from the user POCC. The user could request a specific event (time and link) as the preferred service. The user could also request subsequent ordered choices if the first preference is not available. The user could prioritize request parameters. For example, a specific start time may be prefered over a specific TDRS. In addition, the user could specify in the request that no strategies be used (feast or famine). The information exchange necessary for both automated and manual conflict resolution could be facilitated by implementation of a Space Network User Pocc Interface (SNUPI) workstation in which schedule and service flexibility could be graphically displayed and communicated simultaneously at the NCC and user POCC.

## Factors Affecting Conflict Resolution

In addition to user preference, the order and precedence of conflict resolution strategies may be influenced by organizational and operational goals. Candidate organizational goals affecting conflict resolution are:

> NASA established user POCC priority. This places more emphasis on the higher priority users getting their first preference for conflict resolution strategies.
>
> Resource utilization schemes. The NCC may wish that certain users be assigned specific ATDRS or ATDRS links. The NCC may wish to avoid scheduling on one satellite, for example, the spare, except when no other conflict resolution strategy will work. The NCC may wish to maximize utilization of single resources, or ensure a leveling of resource utilization across the system. Each of these schemes would impact the application of conflict resolution strategies.
>
> Rewarding cooperation. The NCC may use priority in conflict resolution to reward a user POCC for following the SN rules. For example, the POCC that always has requests in on time, has maximum flexibility in each request, or is willing to give up a service during a conflict, may be rewarded in future scheduling by increasing the priority of its conflict resolution strategies.

In an effort to achieve schedule stability, there may be operational limitations that affect the application of conflict resolution strategies.

> Development (forecast) period. All applicable strategies would be used on all requests.
>
> Maintenance period. Strategies that go beyond specific request tolerances for scheduled requests would not used, but all applicable strategies would be used for a request added in this period. Within twenty four hours of a service, no strategies would be used on previously scheduled requests.
>
> Spacecraft emergencies. All applicable strategies would be used to ensure the emergency is scheduled without conflict.

## Schedule Alternatives

If conflict resolution is possible by performing a service in an alternative manner, generated through knowledge embedded in the NCC scheduling system, the alternative must be approved by the user POCC. For example, the user POCC may have requested an

SSA forward service that can be satisfied only by substituting an available SMA forward service. The knowledge in the system indicates that for an SSA conflict, the user satellite is capable of receiving the SMA forward, and the user POCC has accepted the SMA forward alternative in the past, but the service duration must be increased. The system checks Field of View data to determine if the longer duration service is applicable to the user satellite. The knowledge in the system may also indicate whether such a substitution is possible without advanced user confirmation. In either case, the alternative would be communicated to the user for confirmation before or after scheduling.

### Manual Conflict Resolution

In spite of automating the conflict resolution process, special circumstances will occur in the ATDRSS era requiring manual conflict resolution by the SN scheduling analyst. Examples include when two user POCCs having the same priority (Space Station and Space Shuttle) have a resource conflict, when spacecraft emergencies conflict with higher priority user POCC schedules, or when a service bumps a lower priority user POCC less than twenty-four hours before the service. The analyst will have the capability to manually move, fix, or delete a service request from the system. Once a service conflict is manually resolved by the analyst, it cannot be moved as part of further automatic conflict resolution until the analyst removes the override.

## CONFLICT RESOLUTION STRATEGIES

In order to resolve conflicts, there must be conflict resolution strategies. Potential strategies include:

(1) Priority. The user POCC having the highest priority established by NASA for both spacecraft and mission, will have its service placed on the schedule ahead of a lower priority user service. Goodness of schedule may be determined by how many highest priority user services are placed on the schedule using the highest priority conflict resolution strategy.

(2) Moving a service in time, by moving the request start time forward or backward within a tolerance window.

(3) Moving a service to the previous or next valid view period appropriate for that spacecraft.

(4) Switching to an alternate resource. If the request can be satisfied by a resource not specifically requested, the requested but unavailable resource may be replaced by the alternate, available resource. An example might be an MA forward service replacing an unavailable SSA forward service.

(5) Shrinking a service duration. It may be acceptable to decrease the duration of a service by a few minutes in order to allow it to fit on the schedule, as an alternative to denying the service request. After a service has been shrunk, it may be moved forward or backward within tolerance. This may be particularly applicable to forward services which currently schedule more time than is normally used.

(6) Breaking up a prototype event into individual services, and performing separate conflict resolution strategies on the individual services. Relationships between services, both temporal and logical, must be specified, and considered so that individual conflict resolution does not invalidate the entire requested event.

(7) Breaking up a service into multiple discontinuous services, or gapping. It may be acceptable to break up a requested service into two shorter services separated by a small, conflicting higher priority request. An example of such a service may be a tape playback that can be interrupted and resumed.

(8) Combinations of the above strategies.

(9) Deleting a service from the schedule. A higher priority request may be scheduled by deleting a lower priority request from the schedule, eliminating the conflict.

## AUTOMATED CONFLICT RESOLUTION IMPLEMENTATIONS

Some of the automated conflict resolution concepts mentioned here are already implemented in existing scheduling systems.

Plan-IT-2 developed by the Jet Propulsion Laboratory allows the scheduling analyst to explicitly invoke tactical plans for automatic scheduling, or read them in from a script file. The conflict resolution tactics specify what strategies to implement and in what order.

The Experiment Scheduling Program (ESP)2, developed at Marshall Space Flight Center, allows users to specify weighting factors for each of the parameters in a schedule request. In this way, preferences can be specified for order of application, and the "goodness" of the resultant schedule can be quantified by the sum of the weights.

## DISCUSSION TOPICS

The following issues relevant to this paper should be discussed during the working session:

What specific conflict resolution strategies are applicable to the user POCCs?
How much would conflict resolution strategies and preferences vary between services of a specific user POCC?
How much would conflict resolution strategies and preferences vary between different user POCCs?
Does a hierarchy of strategy preferences exist?
Under what circumstances should manual conflict resolution be required?
How amenable to automatic conflict resolution are user POCCs?
How much and what type of tolerance could be communicated to the NCC from user POCCs?
How much would tolerances vary between services of a specific user POCC?

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# A Method for Interference Mitigation in Space Communications Scheduling

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**Abstract**

Increases in the number of user spacecraft and data rates supported by NASA's Tracking and Data Relay Satellite System (TDRSS) in the S and Ku bands could result in communications conflicts due to mutual interference. More attention must be paid to this problem in terms of communications scheduling. A method to mitigate interference while minimizing unnecessary scheduling restrictions on both TDRSS network and user resources, based on consideration of all relevant communications parameters, has been developed. The steps of this method calculate required separation angles at TDRS and produce potential interference intervals, which can be used in the production of schedules free of unacceptable interference. The method also can be used as the basis for analysis, evaluation, and optimization of user schedules with respect to communications performance. This paper describes the proposed method and its potential application to scheduling in space communications. Test cases relative to planned missions, including Earth Observing System, Space Station Manned Base, and Space Shuttle, are discussed.

**Introduction**

Scheduling of user spacecraft communications utilizing the geosynchronous data relay satellites of NASA's Tracking and Data Relay Satellite System (TDRSS) (Figure 1) must increasingly be concerned with the effects of mutual interference between users. While current techniques for interference mitigation are adequate for scheduling under light system loading, the concerns regarding mutual interference will become more serious with projected increases in loading, especially in the late 1990s and beyond (NASA Goddard Space Flight Center, forthcoming).

Consideration of the effect of communications factors such as signal to interference ratio (S/I), BER margin degradation, and power received is beyond the scope of current TDRSS network scheduling systems.

Furthermore, link margins are always constrained to the minimum acceptable value by the high costs associated with designing, building, and orbiting spacecraft with higher margins. Consequently, mutual interference would become more likely, and would tend to be more serious whenever it should occur.

The ultimate objective is to schedule interference-free communications while minimizing constraints imposed both on user spacecraft missions and on the use of TDRSS resources. This objective cannot be accomplished absent the capability to analyze, evaluate, and optimize user schedules with respect to communications performance.

The Communications Link Analysis and Simulation System (CLASS) developed by NASA Goddard Space Flight Center (GSFC) is a software tool for the prediction and evaluation of TDRSS/user spacecraft communications link performance. CLASS is a unique system designed to consider all communications channel parameters that affect link performance, including interference (NASA Goddard Space Flight Center, 1989, September).

The need for a capability that considers all relevant communications parameters in the analysis, evaluation, and optimization of user schedules relative to mutual interference has led to the development of such a capability within CLASS.

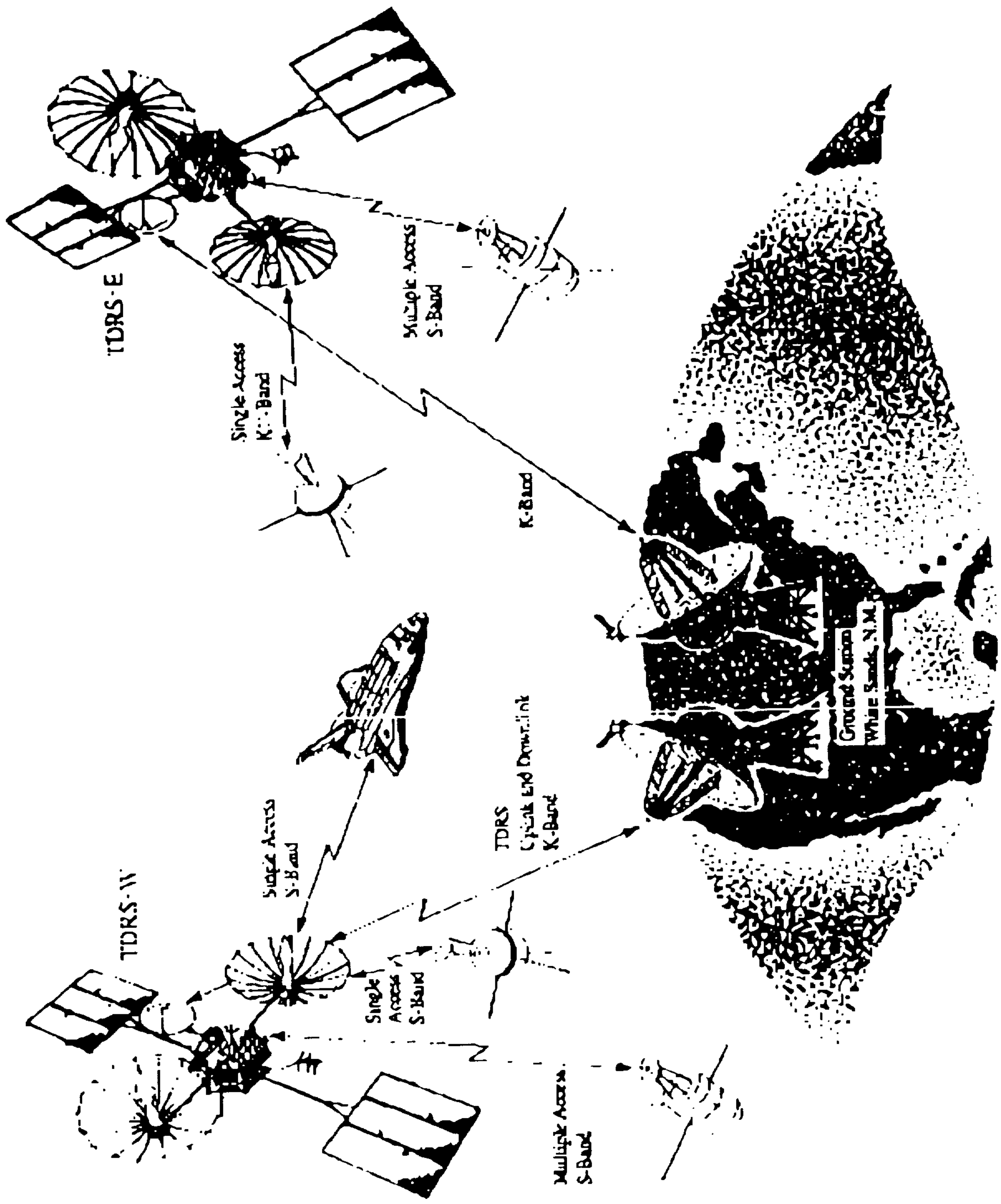



Figure 1. TDRSS Configuration.

An overview of TDRSS telecommunications is presented in the next section. The subsequent sections describe the proposed approach and present illustrative test cases. A discussion of results is then offered, along with a summary and an indication of directions for future work.

### TDRSS Telecommunications Overview

NASA's Tracking and Data Relay Satellite System consists of a space segment and a ground segment as shown in Figure 1. The ground segment of TDRSS consists of a ground terminal at White Sands, New Mexico. The operational space segment consists of a user transponder on each user spacecraft, and three in-service satellites in geostationary orbit at 41, 171, and 174 degrees west longitude. In the future, a cluster of two TDRS's 3 degrees apart may be placed in operation at each of the approximate positions of 41 and 171 degrees west longitude.

TDRSS provides telecommunications in S band via single access (SA) and multiple access (MA) service, and in Ku band via the SA service. Forward links (signals from ground station via TDRS to user) operate at data rates from 0.1 Kbps to 25 Mbps, and return links (signals from user to ground station via TDRS) operate at data rates from 0.1 Kbps to 300 Mbps (NASA Goddard Space Flight Center, 1988, September).

Each TDRS may support a maximum of five forward links: two S-band and two K-band on each of the two SA antennas and one S-band on the MA system. By design, each TDRS may support a maximum of 24 return links: 20 on the MA antenna, two at S-band on SA (SSA), and two at K-band on SA (KSA). Future TDRS cluster operations will approximately double the resources available at each of the two geostationary positions at 41 and 171 degrees west longitude.

The information necessary to characterize the communication systems of TDRSS and user spacecraft, such as antenna type, coding scheme, data rate, signal level, or polarization, as well as the channel environments, is maintained in CLASS data bases. All possible sources of effects on the RF signal are taken into account, including vehicle and earth multipath, vehicle blockage, atmospherics, and signal reflections from terrestrial surfaces.

### Interference Analysis Considerations

Since all TDRS forward links are PN spread, and since the data rates are less than or equal to 300 Kbps, the PN processing gain over interference will be at least 10 dB. Therefore, interference on desired user forward channels can be neglected.

The interference problem between two return links is more complicated because data rates on return links in general are much higher than on forward links, and because the links may or may not be PN spread and may or may not be cross polarized. Hence, in this paper, interference mitigation is concerned only with the user return channel.

The problem of multiple simultaneous interferers is not considered in this paper.

### A Model for Communications Performance in the Presence of Mutual Interference

The proposed approach to interference mitigation uses BER margin degradation, formulated as a function of signal to interference level ratio (S/I), as the basic parameter for determination of channel communications performance for a link in the presence of interference (Bhargava, 1981). BER margin degradation includes all the factors in the ground receiver (data rate (bandwidth) difference between the desired user and interferer, and implementation loss), and fully reflects channel performance when interference exists.

Figure 2 shows the relationship between BER degradation and S/I in a representative case.

Nonnegative BER margin is considered to correspond to acceptable communications performance when a link is degraded by interference. In general, degradation is computed by simulation, with S/I as an input parameter.

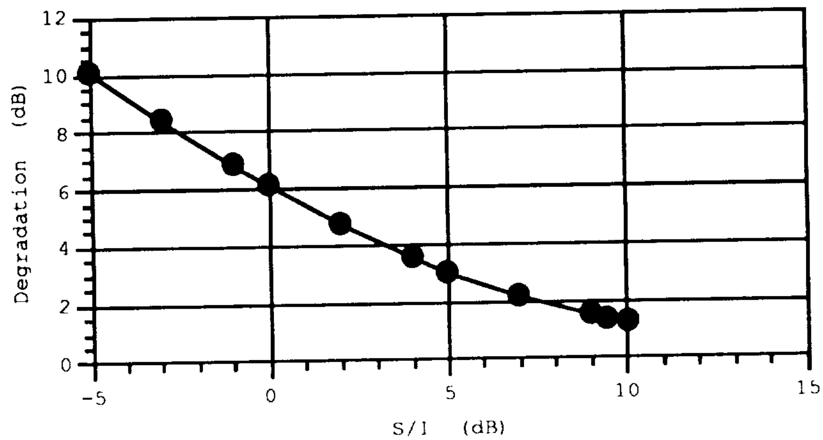



Figure 2. Computed relationship between degradation and S/I for the case where the desired user is the Space Shuttle Orbiter using channel 3, 50 Mbps coded, and the interferer (assumed to be on the TDRS SA antenna boresight) is Space Station Freedom using the 50 Mbps (I+Q) link. The desired user and interferer links are cross polarized with an assumed polarization rejection of the interfering signal of 15 dB on the TDRS SA antenna boresight.

The signal to interference level ratio S/I in dB at TDRS is defined as a function of the separation angle α between the desired user and the interferer as seen from TDRS:

$$\frac{S}{I}(\alpha) = \left(P_d + G(0)\right) - \left(P_i + G(\alpha) + R(\alpha)\right) + G_p + A_p + L_{fs} \quad (1)$$

where

$P_d$ = the worst case (maximum range) TDRS received power at unity antenna gain for the desired user (in dB) including the loss due to the nonperfect polarization match between the TDRS and desired user antennas. It is assumed that the desired user is on the TDRS antenna boresight and that the desired user's antenna is pointing toward TDRS. $P_d$ includes contributions from stochastic sources such as multipath (vehicle, earth, and atmospheric) and RFI.

$P_i$ = the best case (minimum range) TDRS received power at unity antenna gain for the interferer (in dB).

G = the TDRS antenna gain (in dB) as a function of the angle α.

R = the polarization rejection of the interferer's signal at the TDRS antenna (in dB) as a function of angle α. R always has a negative value when rejection is present (interferer oppositely polarized ), and is zero otherwise.

$G_p$ = 10 * ALOG10 (Desired user PN chip rate/Desired channel symbol rate) is the processing gain (in dB) of the PN spread signal

$A_p$ = 10 * ALOG10 (Interferer channel PN chip rate/Desired channel symbol rate) is the reduction factor (in dB) if the interferer is PN spread when the desired channel is not PN spread.

$L_{fs}$ = interferer power reduction (in dB) due to frequency separation.

$L_{fs}$ applies to cases (for example, non-TDRS user spacecraft from European or other space agencies) where the frequency separation between the desired user and the interferer is small (less than 10 MHz) but nonzero. Under the current TDRSS design, any two different TDRS-user transmitting frequencies are separated by at least 10 MHz: in such cases, degradation of a desired signal due to a single interfering signal may be neglected.

In case neither desired user nor interferer is PN coded, the adjustment after the match filter at the ground terminal due to a large bandwidth (data rate) difference is included in the degradation calculation.

For QPSK modulation, S/I is calculated for all channels, and since the channel having the smallest S/I will suffer most from interference, the minimum S/I value is used.

Since among the above terms only G and R are functions of $\alpha$, Equation (1) leads immediately to the following for any given $\alpha_1$ and $\alpha_2$, each an allowed value of $\alpha$:

$$\frac{S}{I}(\alpha_2) - \frac{S}{I}(\alpha_1) = -[G(\alpha) + R(\alpha)]_{\alpha=\alpha_1}^{\alpha=\alpha_2} \qquad (2)$$

which expresses the fact that for a given change in $\alpha$, the change in S/I equals the change in the negated adjusted antenna gain: $\Delta(S/I) = -\Delta(G + R)$.

The negated TDRS antenna gain pattern envelope, without polarization adjustment, is shown in Figure 3(a), modeled to represent the main beam, the first null, the peak of the first sidelobe, and a logarithmic relation for the remainder of the pattern.

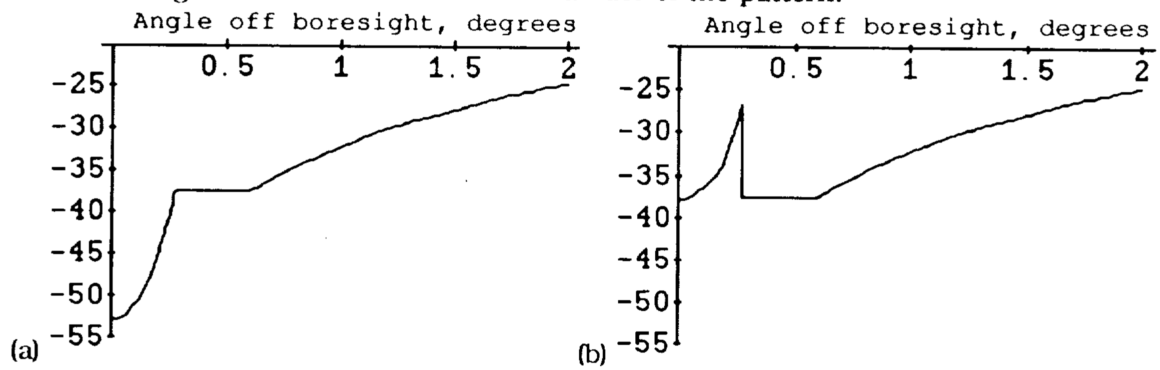



Figure 3. Negated TDRS SA antenna gain pattern envelope: (a) without polarization adjustment, and (b) adjusted by the polarization rejection of a cross polarized signal from an antenna having an axial ratio of 2.1 dB. Note that in both cases, the global minimum of the curve occurs at boresight ($\alpha$ = 0).

Figure 3(b) shows an example of the negated adjusted antenna gain, -[G + R], in which the gain of the TDRS SA antenna is adjusted by the polarization rejection of an oppositely polarized user antenna. (A formulation of polarization rejection at, and a model of the axial ratio of, the TDRS SA antenna are presented in the Appendix.) The transmitting antenna on the interferer (Space Station Manned Base (SSMB)) has a boresight axial ratio of 2.1 dB (a calculated value based on the assumption that the receiving TDRS antenna has a boresight axial ratio of 1 dB and polarization rejection of 15 dB).

In general, the negated adjusted antenna gain curve, -[G + R], will have multiple relative minima. The global minimum value of the curve may correspond to more than one value for the separation angle $\alpha$ (interferer's angle off boresight). We let $\alpha^*$ denote the least such value of $\alpha$.

Of course, it is possible for $\alpha^*$ to be zero. Indeed, if the interferer has the same polarization as the desired user, the polarization rejection at the TDRS SA antenna is zero for all $\alpha$, so that the negated antenna gain (Figure 3(a)) has its global minimum at boresight (under the normal assumption that the antenna gain envelope has its global maximum at boresight). Hence, in this case, $\alpha^* = 0$.

When the interferer and desired user are cross polarized, it is still possible for $\alpha^*$ to be zero, depending on the exact nature of the model used to represent the polarization rejection R. Figure 3(b) illustrates such a possibility, for the case where the interferer is SSMB. As shown in the figure, the global minimum of the adjusted antenna gain -[G + R] occurs at zero degrees off boresight, so that $\alpha^* = 0$ in this example.

From Equation (2), S/I can be expressed as follows:

$$\frac{S}{I}(\alpha) = -[G(\alpha) + R(\alpha)] + \frac{S}{I}(0) + [G(0) + R(0)] \qquad (3)$$

that is, the form of S/I, as a function of angle off boresight, is merely that of the negated adjusted antenna gain, shifted vertically by a constant (the boresight value of S/I plus the boresight value of [G + R]). The graph of S/I is shown in Figure 4 for representative cases (to be described later, in Table 4).

From the S/I graph, it is possible to find a separation angle between the user spacecraft such that no unacceptable interference can occur. This is the basis of the method proposed in this paper for mutual interference mitigation.

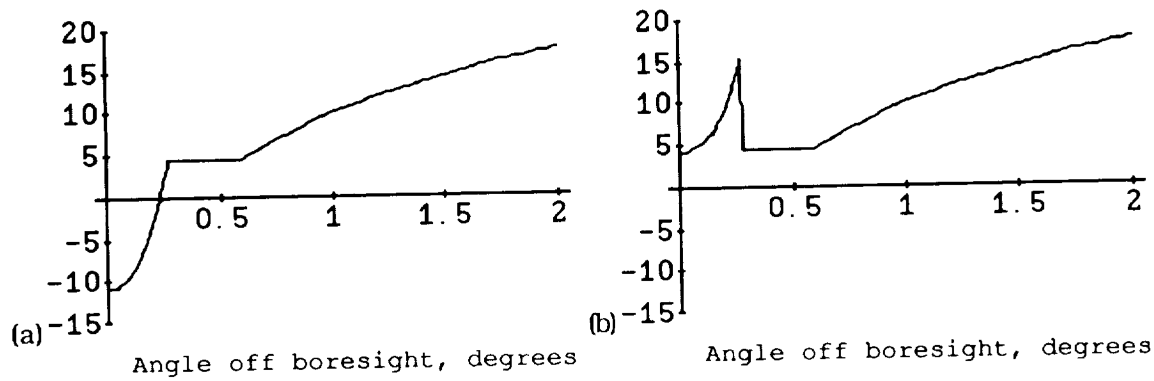



Figure 4. S/I as a function of interferer's angle off boresight: (a) for the case where desired user and interferer have the same polarization, and (b) for a representative case where desired user and interferer are oppositely polarized, showing the effect, on the interfering signal, of TDRS antenna gain and polarization rejection.

*Worst S/I*

As the interferer moves off boresight, the interferer's power $P_i$ changes in a manner dictated by the negated adjusted antenna gain curve. When $-[G + R]$ reaches a local minimum, the interferer's power reaches a local maximum. Since the desired user remains on boresight, $P_d$ remains constant. Therefore, when $-[G + R]$ reaches its global minimum (e.g., at $\alpha=\alpha^*$), the value of S/I will also reach its global minimum. This minimum S/I is the "worst S/I", and so we have, by Equation (3):

$$\left(\frac{S}{I}\right)_{worst} = \frac{S}{I}(\alpha^*) = -\left[G(\alpha^*) + R(\alpha^*)\right] + \frac{S}{I}(0) + \left[G(0) + R(0)\right]$$

Note that if $\alpha^* = 0$,

$$\left(\frac{S}{I}\right)_{worst} = \frac{S}{I}(0)$$

*Required S/I*

The required S/I is defined as the value of S/I such that the degradation of the desired user signal equals the worst case channel margin. Computer simulation is used to obtain the required S/I for any given combination of desired user and interferer links. The worst S/I may or may not be less than the required S/I. If the worst S/I is less than the required S/I, then unacceptable mutual interference is possible for some possible separation angles.

## Interference Mitigation via Separation Angle and Potential Interference Intervals

*Required separation angle*

Since the desired user is assumed to be on the TDRS antenna boresight, and since antenna gain decreases off boresight, a sufficient variation of the interferer's separation angle provides discrimination between the signals, reduces the interference level, and increases the S/I level ratio. In the case where the required S/I is greater than the worst S/I (i.e., where interference is possible) the required S/I corresponds to certain separation angles, which can be read directly from the graph of S/I (see Figure 4). Note that due to the possibility of multiple lobes in the adjusted antenna gain graph (and therefore multiple lobes in the graph of S/I) there may be multiple disjoint ranges of separation angle providing at least the necessary value of S/I. The largest of all the angles where S/I is equal to the required S/I is defined as the required separation angle. Any separation angle not less than this angle assures an acceptable level of interference.

*Potential interference intervals*

A potential interference interval is defined as any time interval during which the separation angle between the two user spacecraft is less than the required separation angle as described above. During such intervals, unacceptable interference could occur if the given pair of links of the two spacecraft are active. The potential interference intervals, therefore, would constrain any interference mitigation scheduling process by specifying when the two links should not be used simultaneously for communications. How to decide which of the two links should not be scheduled during any potential interference interval is part of the algorithm used by the scheduler and is beyond the scope of this paper.

Potential interference intervals are calculated in a straightforward manner, based on given user orbital parameters and the required separation angle.

## A Procedure for Interference Mitigation in Scheduling

A procedure is suggested for producing schedules free of unacceptable interference while minimizing restrictions on use of network and user resources. This procedure is based on a model for communications performance in the presence of interference, on required separation angle, and on potential interference intervals. It is summarized by the following steps:

(1) For every pair of desired and interfering signals, determine $-[G + R]$ as a function of $\alpha$ (the separation angle at a given TDRS between the desired user and the interferer) where G is the TDRS antenna gain envelope and R is the polarization rejection of the interfering signal at the TDRS antenna. R is assumed to be zero if the desired user and interferer have the same polarization.

(2) For every pair of desired and interfering signals, determine the least separation angle at which the function $-[G + R]$ has its global minimum value. Denote this angle $\alpha^*$.

(3) For every pair of desired and interfering signals, determine S/I, the signal to interference level ratio, as a function of $\alpha$ given by Equation (1) above. Calculate $(S/I)(\alpha^*) = (S/I)(0) - [G + R](\alpha^*) + [G + R](0)$. This is the *worst S/I*.

(4) For every pair of desired and interfering signals, determine by computer simulation the degradation of the desired signal that corresponds to $S/I(\alpha^{*})$. This is the desired signal's *worst degradation*. Identify all signal pairs where the desired signal's worst degradation exceeds the desired user's worst link margin. Mutual interference will be unacceptable for these signal pairs.

(5) For every pair of desired and interfering signals where interference is unacceptable as determined in step (4), determine by computer simulation the *required S/I*, i.e., the S/I for which the degradation is equal to the desired signal's worst link margin.

(6) For every pair of desired and interfering signals where interference is unacceptable as determined in step (4), calculate the required separation angle (the largest separation angle between the desired user and interferer that provides the required S/I as determined in step (5)).

(7) For every pair of desired and interfering signals where interference is unacceptable as determined in step (4), and on the basis of the separation angles obtained in step (6), find all *potential interference intervals*, that is, intervals during which unacceptable interference is possible.

(8) Use the potential interference intervals from step (7) as a constraint to a scheduler for generating schedules free of unacceptable interference. The effect of this constraint is to preclude the scheduling of any combination of desired/interferer links during any potential interference interval associated with that combination of links.

The first four steps can be used as a screening process to isolate the cases where unacceptable interference could occur. Steps (5) and (6) would be applied in such cases, as an intermediate process prior to execution of a scheduling system. Step (7) would be performed prior to every run of an interference mitigation scheduling system (step (8)).

**Implementation**

Software to produce potential interference intervals has been implemented within the CLASS environment as an initial step toward development of a scheduling system (illustrated in Figure 5) that incorporates the interference mitigation methodology described in this paper.

The principal components of the software are the analysis system, the required separation angle calculator, and the potential interference interval calculator. Each of these elements accesses the "interference analysis table".

The analysis system accesses CLASS data bases containing link parameters (e.g., data rate, coding scheme, polarization, power), orbital elements, et cetera, in order to calculate required S/I, worst S/I, and worst degradation. These calculated values are stored into the interference analysis table for use by the required separation angle calculator. The required separation angle calculator also takes input from a file containing orbit and view period data.

Output from the required separation angle calculator is written into the interference analysis table.

The potential interference interval calculator reads the required separation angles and calculates all intervals during which every pair of potentially-interfering spacecraft have a separation less than the required separation angle. The potential interference intervals are written into a file, which can then be used as input to a scheduler.

Each line (record) in the interference analysis table consists of the following items:

(1) Desired User ID

(2) Desired User Link ID
(3) Desired User Channel
(4) Desired User Polarization
(5) Interferer ID
(6) Interferer Link ID
(7) Interferer Polarization
(8) Interferer Antenna Boresight Axial Ratio
(9) TDRS SA Antenna ID
(10) Desired User Worst Case Link Margin
(11) Required S/I
(12) Worst S/I
(13) Worst Degradation
(14) Required Separation Angle

# IMSS Block Diagram

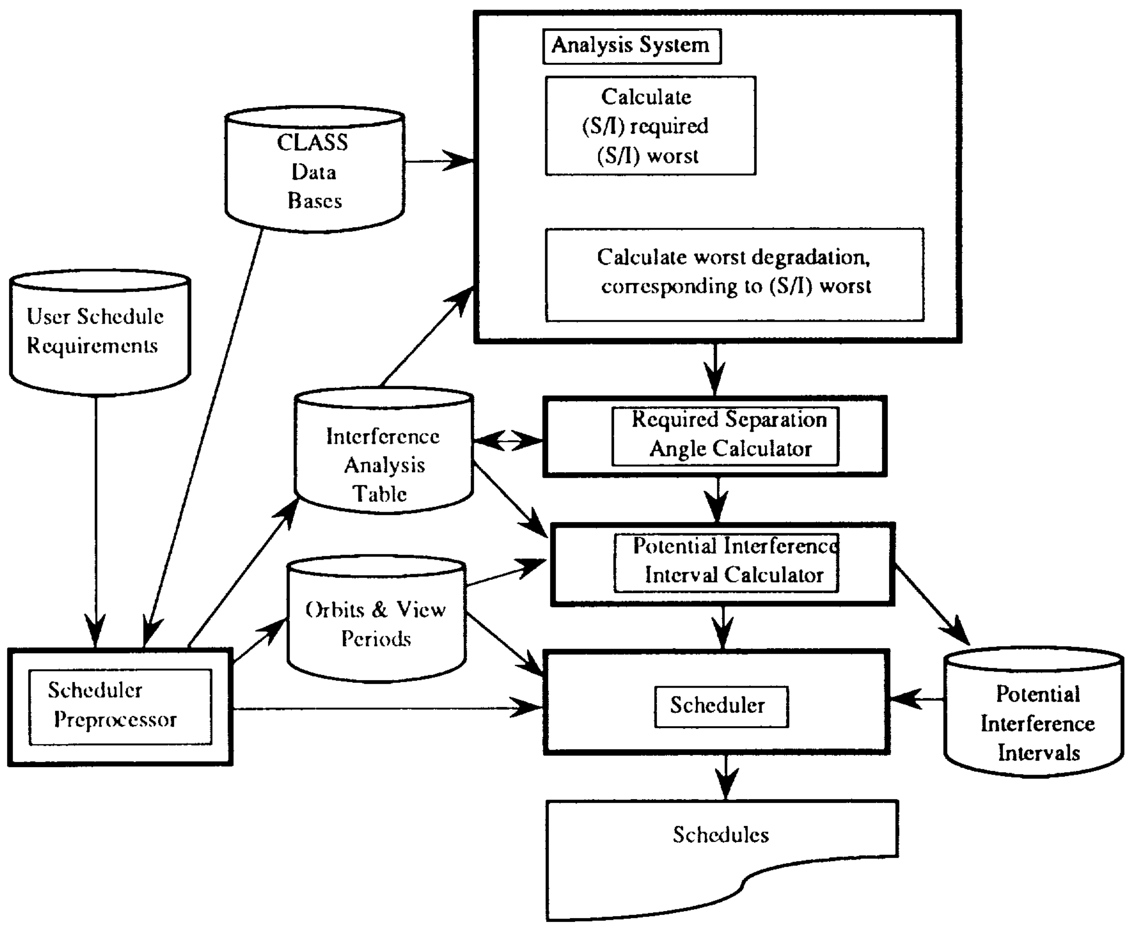



Figure 5. Block diagram of the proposed interference mitigation scheduling system (IMSS). The modules represented by the shaded blocks produce the potential interference intervals, and have been implemented in Goddard Space Flight Center's Communications Link Analysis and Simulation System (CLASS).

## Application of the Approach: A Numerical Example

The proposed interference mitigation approach has been applied to planned missions including Space Shuttle Orbiter (SSO), Space Station Manned Base (SSMB), and Earth Observing System (EOS).

The relevant communications parameters for these three missions, as obtained from an internal GSFC memorandum (NASA/GSFC, 1989, January 30) concerning Shuttle links, and from RF Interface Control Documents (NASA/GSFC, 1989, October 27; NASA/GSFC, 1990, February), are presented below.

All the missions in this example operate at Ku band with carrier frequency equal to 15.0034 GHZ, unspread.

SSO operates with Right Circular Polarization (RCP). Table 1 presents the link characteristics.

Table 1. Space Shuttle Orbiter Link Characteristics

| CHANNEL | DATA RATE (kbps) | EIRP (dBW) | LINK MARGIN (dB) |
|---|---|---|---|
| Channel 1: Subcarrier Q | 192 | 39.4 | 19.0 |
| Channel 2: Subcarrier I | 2,000 | 43.6 | 13.5 |
| Channel 3: Baseband | 50,000 | 51.0 | 1.5 |

Channels 1 and 2 are rate 1/2 convolutional coded and channel 3 is uncoded.

SSMB operates with Left Circular Polarization (LCP) at data rates of 300 Mbps and 50 Mbps. Table 2 presents the link characteristics.

Table 2. Space Station Manned Base Link Characteristics

| CHANNEL | DATA RATE (Mbps) | EIRP (dBW) | LINK MARGIN (dB) |
|---|---|---|---|
| I | 150 | 57.1 | 3.0 |
| Q | 150 | 57.1 | 3.0 |
| I | 25 | 57.1 | 10.8 |
| Q | 25 | 57.1 | 10.8 |

The parameters given above for SSMB are preliminary and subject to change.

EOS operates with RCP at data rates of 300 Mbps. Table 3 presents the link characteristics.

Table 3. Earth Observing System Link Characteristics

| CHANNEL | DATA RATE (Mbps) | EIRP (dBW) | LINK MARGIN (dB) |
|---|---|---|---|
| I | 150 | 57.6 | 3.6 |
| Q | 150 | 57.6 | 3.6 |

*Interference analysis results*

Table 4 presents the results of interference analysis. In Case 1, where the SSO (COLUMBIA) channel 3 (50 Mbps) experiences interference from the EOS 300 Mbps link (I + Q), the required S/I exceeds the worst S/I by 17.8 dB. The required separation angle to mitigate interference, which can be obtained directly from the appropriate S/I graph (Figure 4(a), with a required S/I of 6.2 dB), is 0.74 degrees. There is no unacceptable interference for SSO channels 1 and 2.

Table 4. Interference analysis table.

| | | Case 1 | Case 2 |
|---|---|---|---|
| Desired User | User ID | COLUMBIA | COLUMBIA |
| | Channel | Z | Z |
| | Polarization | RHC | RHC |
| | Worst Case Margin | 1.5 | 1.5 |
| Interferer | User ID | EOS | SSMB |
| | Polarization | RHC | LHC |
| | Axial Ratio (dB) | 1.5 | 2.1* |
| TDRS | SA Antenna ID | DEFLT | DEFLT |
| S/I | Required (dB) | 6.2** | 9.0** |
| | Worst (dB) | -11.6 | 4.0 |
| Worst Degradatation (dB) | | ** | ** |
| Required Separation Angle (deg) | | 0.74 | 0.92 |

*NOTE: In this case, the axial ratio for the interferer's antenna is a calculated value based on an assumed value of 15 dB for the polarization rejection of the interferer's link on the boresight of the TDRS SA antenna.

**NOTE: Obtained by computer simulation.

In Case 2, in which the interferer is the SSMB 50 Mbps link (I + Q), the required S/I, 9.0 dB, is greater than the worst S/I by 5.5 dB, and from Figure 4(b) the required separation angle is 0.96 degrees. There is no unacceptable interference for SSO channels 1 and 2.

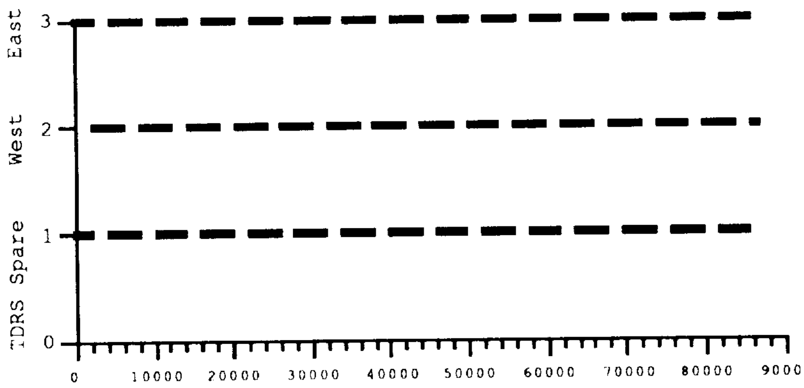
There is no unacceptable interference between the SSMB 300 Mbps link (I + Q) and the SSO channels 1, 2, and 3.

*Potential Interference Intervals*

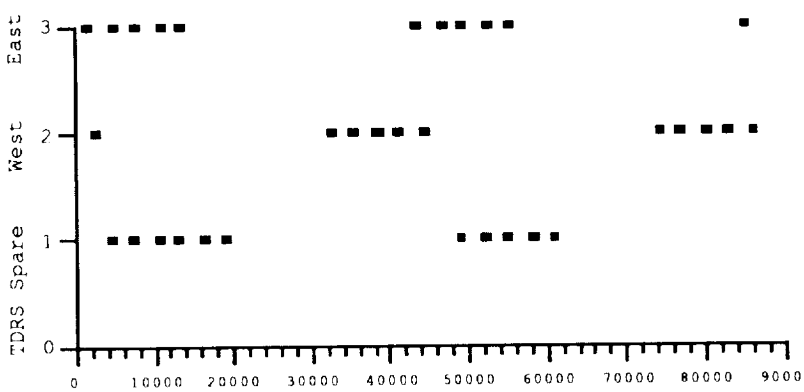
Potential interference intervals depend closely on the choice of orbits for user spacecraft. Figure 6 illustrates this dependency by showing the intervals for two choices for the user orbital elements. The only difference between these choices is the value for the mean anomaly. For the choice illustrated in Figure 6 (a), the difference in the mean anomaly is 0 degrees, and for the choice illustrated in Figure 6 (b), it is 20 degrees. The total of the potential interference intervals goes from 100% of the in-view time (Figure 6 (a))--approximately 813 minutes during the 24 hour scheduling period--to approximately 61 minutes (Figure 6 (b)). Thus, the potential interference intervals become shorter and less numerous as the orbital spacing of the users increases. Indeed, whenever the mean anomalies differ by more than approximately ___ degrees, with all other factors remaining the same, unacceptable interference becomes impossible and potential interference intervals no longer exist.

**Application of Potential Interference Intervals in Existing Scheduling Systems**

Potential interference intervals also can be used in analyzing, evaluating and optimizing user schedules generated by current scheduling systems with respect to communications performance. The simultaneous communnications contacts specified in any given schedule, produced by any scheduling system, can be compared with the potential interference intervals produced by the above procedure, in order to discover interference problems. Each such problem could then be evaluated relative to actual mission needs, priorities, or other aspects of the scheduling process. If a schedule revision is decided upon, by either a manual or an automated procedure, it could also be similarly checked and evaluated. Further, the degree to which schedules are free of mutual interference based on the potential interference intervals discussed in this paper could be used as a measure by which to evaluate them relative to each other or relative to a standard. Given the capability to generate different alternative schedules, the ability to evaluate schedules then implies the ability to optimize schedules with respect to communications performance. However, it would seem preferable to incorporate into the scheduler itself the ability to generate schedules directly reflecting the constraint of potential interference intervals (step (8) in the proposed procedure).




(a)




(b)

Figure 6. Potential Interference Intervals at (1) TDRS Spare, (2) TDRS West, and (3) TDRS East when the desired user is SSO COLUMBIA and the interferer is Space Station. A period of twenty-four hours is represented. Each user spacecraft orbit is approximately 90 minutes in duration. (a) The users have identical orbits, so that the separation angle is always zero degrees during TDRS view periods. Thus, potential interference occupies 100% of in-view time. (b) The users have identical orbits except for a 20 degree difference in their mean anomalies. In each orbit there are two times when they are separated by less than the required separation angle: once just after appearing above the horizon as seen by the TDRS, and once just before disappearing below the horizon.

**Summary**

The key proposition of this paper is that an interference mitigation scheduling system (i.e., a system capable of producing schedules that are free of unacceptable interference and that minimize unnecessary restrictions on network and user resources) must reflect consideration of communications performance. The concept of using BER degradation as a function of S/I, as presented above, is a sufficient basis for an interference mitigation scheduling system.

In general, scheduling may involve any number of different user spacecraft. The scope of the approach presented in this paper is limited to the case of single interferers. The case of multiple interferers is left for future work.

This paper presents a model of communications performance affected by the presence of mutual interference. The model formulates communications performance in terms of S/I, which is considered as a function of the interferer's angle off boresight. Required separation angles for interference mitigation can be calculated based on this functional ralationship, and these angles then can be used to determine potential interference intervals (intervals during which mutual interference could occur).

Potential interference intervals are proposed for use as a constraint by an interference mitigation scheduler. Used as a constraint, a potential interference interval disallows simultaneous communications by both of the links associated with the interval. By guaranteeing acceptable BER degradation for all desired user/interferer link combinations, except during the potential interference intervals associated with those link combinations, the proposed procedure guarantees schedules to be free of unacceptable mutual interference. Potential interference intervals also can be useful as the basis for evaluating and optimizing (with respect to communications performance) the user schedules produced by any scheduling system.

The method presented in this paper offers a feasible, general approach to mutual interference mitigation as a means for generating schedules free of unacceptable interference.

**Future Work**

A scheduling system incorporating the approach described in this paper is being developed in the CLASS environment for use in mission planning and in communications performance optimization of user schedules. The effect of multiple interferers is to be considered in a later effort.

**Acknowledgments**

The authors would like to thank CLASS Project Manager Robert Godfrey of NASA/GSFC for originating the concept of an interference mitigation scheduling system for CLASS. We would also like to thank Nancy Smith Ron Vento of NASA/GSFC; Farzad Ghazvinian and Masoud Toufanian of LinCom Corporation and David Wampler of Stanford Telecommunications for valuable technical support; and our supervisor, Frank Stocklin, for his encouragement of our efforts on this project.

**References**

Bhargava, Vijay K., Haccoun, D., Matyas, R., & Nuspl, P. P. (1981). *Digital Communications by Satellite*. New York, NY: John Wiley & Sons.

NASA Goddard Space Flight Center (forthcoming). *Space Network Support Capability Study*, STDN No. 114, Revision 4. Greenbelt, Maryland.

NASA Goddard Space Flight Center (1988, September). *TDRS User Guide*, STDN No. 101.2, Revision 6. Greenbelt, Maryland.

NASA Goddard Space Flight Center (1989, January 30). Memo, Subject: STS Link Calculations, To Distribution, From GSFC Code 531.1. Greenbelt, Maryland.

NASA Goddard Space Flight Center (1989, September). *Communication Link Analysis and Simulation System*, CLASS No. 101. Greenbelt, Maryland.

NASA Goddard Space Flight Center (1989, October 27). *Radio Frequency Interface Control Document Between the Space Station Project and the Tracking and Data Relay Satellite System* (Preliminary Baseline). Greenbelt, Maryland.

NASA Goddard Space Flight Center (1990, February). *Radio Frequency Interface Control Document Between the EOS Platform and the Tracking and Data Relay Satellite System* (Preliminary Baseline). Greenbelt, Maryland.

Computer Sciences Corporation (1990, February). *Network Control Center User Planning System System Requirements Document.* NASA Goddard Space Flight Center, Greenbelt, Maryland.

Welti, George, Christopher, P., & Griffin, M. (1990, 9 March). *ATDRSS Self-interference Assessment.* Technical Report TR90007, Stanford Telecommunications, Inc., Reston, VA.

NASA Goddard Space Flight Center (1990, April/May). *Mission Requirements and Data Systems Support Forecast*, STDN No. 803. Greenbelt, Maryland.

## Appendix

*Polarization Rejection*

Polarization rejection, R, of the interfering signal at the oppositely polarized TDRS SA antenna is a function of the TDRS SA antenna axial ratio $r_w$ (not in dB) and the interferer antenna axial ratio $r_a$ (not in dB) :

$$R = 10\, Log \left[ \frac{1 + \rho_w^2 \rho_a^2 + 2\, \rho_w\, \rho_a \cos(2\theta)}{\left(1 + \rho_w^2\right)\left(1 + \rho_a^2\right)} \right] dB$$

where
$$\rho_w = \frac{r_w + 1}{r_w - 1},$$

Note that
$$\rho_a = \frac{r_a + 1}{r_a - 1},$$

and where $\theta$ is the angular orientation of the electric field vector. The axial ratio is negative for right circular polarization (RCP) and positive for left circular polarization (LCP) .

In the present application, $\theta$ is assumed to be zero degrees in keeping with the assumption of the maximum effect of the interferer.

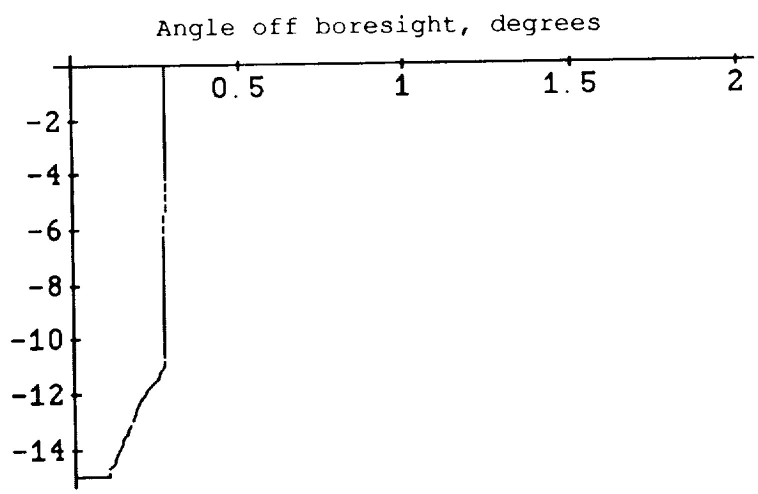



Figure A. Polarization rejection modeled as a function of angle off boresight at the TDRS SA antenna when the transmitting antenna is that of the Space Station Manned Base.

Figure A shows the polarization rejection as a function of angle off boresight in the case of the TDRS SA antenna as the receiving antenna and the Space Station Manned Base high gain antenna as the transmitting antenna. The boresight axial ratios are 1.0 dB and 2.1 dB, respectively. Axial ratio off boresight for the receiving antenna is modeled as described in the following section. Note that beyond the first null, since the axial ratio is undefined, the polarization rejection is also undefined.

*Antenna Axial Ratio Model*

The axial ratio of the TDRS SA antenna is modeled as a function of angle off boresight. Let $a$ denote the angle off boresight at which the gain is 3 dB down from the boresight gain, and let $b$ denote the angle off boresight at the first null in the gain pattern. Beyond the first null, the axial ratio is undefined. The axial ratio in dB is then modeled as a broken straight line function of angle $\alpha$ off boresight:

$$r(\alpha) = \begin{cases} 1 \quad dB, & if\, 0 \le \alpha \le a \\ \left(\dfrac{2}{b-a}\,\alpha + \dfrac{b-3a}{b-a}\right) \quad dB, & if\, a \le \alpha \le b \\ undefined, & if\, \alpha > b \end{cases}$$

Note that $$r(\alpha) = \begin{cases} 20\, Log\, r_w & for\ the\ transmitting\ antenna \\ 20\, Log\, r_a & for\ the\ receiving\ antenna \end{cases}$$

This model is illustrated in Figure B using values for $a$ and $b$ of 0.1 degrees and 0.274 degrees, respectively.

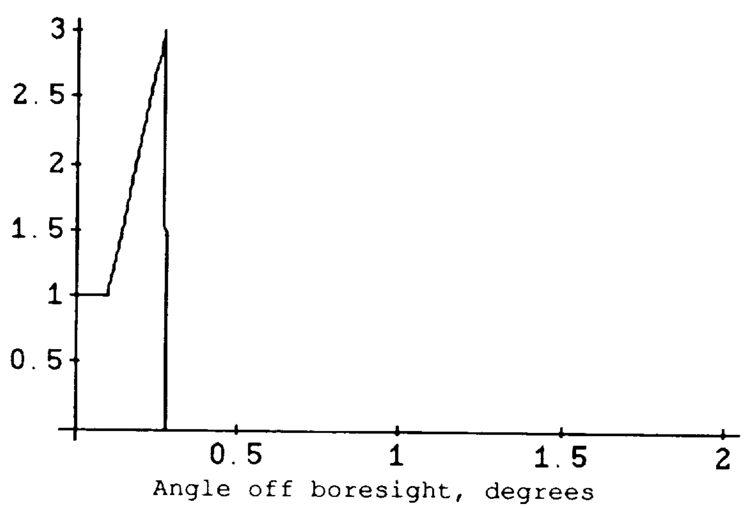



Figure B. Axial ratio modeled as a function of angle off boresight for the TDRS SA antenna.

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# A Planning Language for Activity Scheduling

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## Abstract

Mission planning and scheduling of spacecraft operations are becoming more complex at NASA. Spacecraft contain increasingly powerful onboard computers which may be commanded to a vast number of modes and configurations. Automated planning and scheduling tools are needed to support the dramatic increase in capabilities, system performance, and user flexibilities. This paper describes a mission planning process; a robust, flexible planning language for spacecraft and payload operations; and a software scheduling system that generates schedules based on the planning language inputs. The mission planning process often involves many people and organizations. Consequently, a planning language is needed to facilitate communication, to provide a standard interface, and to represent flexible requirements. The software scheduling system interprets the planning language and uses the resource, time duration, constraint, and alternative plan flexibilities to resolve scheduling conflicts.

## 1 Background

NASA performs several types of scheduling. Each type requires different approaches and tools. Examples of types of scheduling include the following:

• *project scheduling*: Tracking the progress of a project development team.

• *payload manifesting*: Determining the payload manifests for Space Shuttle missions.

• *job shop scheduling*: Refurbishing four Space Shuttles for repeated launches.

• *activity scheduling*: Arranging activities to produce a time line of operations and procedures.

The concepts, approaches, and systems described in this paper apply specifically to activity scheduling, which is a part of the mission planning and scheduling process.

We are concerned with the planning and scheduling of NASA mission operations with respect to spacecraft, flight instruments, space and ground communications networks, and NASA customers (science, application, and commercial users). In our applications, planning consists of deciding which instrument activities, spacecraft activities, and ground activities to perform, while scheduling consists of allocating resources to the activities and sequencing them onto a time line to produce a schedule. Planning is performed by mission planners and science users. Scheduling is currently performed manually with varying degrees of computer assistance but, as we show here, can become highly automated. We focus on the short term time frame from four weeks before an activity occurs to the actual real time support of an activity. Strategic planning and tactical planning involve long-term planning conducted months and years in advance and are outside of our planning process except that their products, the mission goals, serve as inputs to our applications.

Activity scheduling includes allocating resources and assigning times to spacecraft and instrument activities. If resources are scarce, one must decide which activities cannot be scheduled. Temporal constraints between activities restrict activity scheduling (e.g., Activity A must be scheduled before Activity B).

Several techniques are available for generating conflict-free schedules, including hybrid neural network/heuristic approaches as described in [Gaspin, 1989], heuristic approaches as described in [Berner, 1989], and, if the problem is sufficiently constrained, mathematical programming approaches (linear and nonlinear) as in [Reddy, 1989]. Techniques for improving an existing schedule include a neural network approach as described in [Sponsler

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and Johnston, 1990] and a best-first search approach as described in [Odubiyi and Zoch, 1989].

As flexibilities are added to plans, the scheduling procedure becomes more complex. For instance, if specific resource requirements, start times, and end times for an activity are requested, a scheduling system can respond with a yes or no. If flexible resource requirements and general temporal requirements are specified instead of specific requirements, the scheduling software must search the current schedule for places where temporal requirements and resource requirements are met. If nominal resource requirements cannot be met, the scheduling system can utilize the specified resource flexibilities and try again to schedule the activity. For example, instead of specifying a request for a 10-minute communication with TDRS-E (Tracking and Data Relay Satellite, East) at 3 p.m. on a certain day, a plan might specify that communication with either TDRS (East or West) is needed between 2 p.m. and 4 p.m.

The Data Systems Technology Division (Code 520) at Goddard Space Flight Center has developed a testbed to investigate the scheduling process for increasingly complex future NASA missions. The testbed includes a mission planning and scheduling system called the Request-Oriented Scheduling Engine (ROSE), that addresses the activity scheduling problem. Spacecraft operation plans are input to ROSE in a robust planning language called the Flexible Envelope Request Notation (FERN).

In this paper we describe (1) the need for increased automation in mission planning and scheduling, (2) the mission planning and scheduling process, (3) the FERN, and (4) the ROSE.

## 2 The Need for Automation

Several factors motivate the need for increased automation. These factors include the complexity of flight instruments and spacecraft, the need to provide increased flexibility to users, the need for safety, and the support for complex, distributed scheduling architectures. Each factor is discussed below.

### 2.1 Complexity of Flight Systems

NASA flight instruments and spacecraft are physically larger and more complex than past space systems. Past space systems were relatively simple since there was no way to repair onboard hardware failures. Now, the Space Shuttle crew can repair and service low-earth orbiting spacecraft. Thus, a major obstacle that restrained complexity has been removed for many missions.

Increasingly powerful onboard computers have greatly expanded the capabilities of flight systems which may be commanded to a vast number of modes and configurations. Automated scheduling systems on the ground are needed to support the automated flight systems and keep track of operation time lines which contain numerous constraint and activity relationships. Manual scheduling is becoming impractical.

### 2.2 The Need for Flexibility

Presently, instrument and spacecraft activities are conducted according to an operations time line developed ahead of time. Users want a more flexible approach that allows real-time user interactions with instruments. They want the capability to select and perform different activities based on the results of real-time telemetry without going through a lengthy rescheduling process. Scientists often wish to re-plan operations to react to a "target of opportunity" (an interesting phenomenon such as a significant sun flare, volcano, or hurricane). Rapid, safe rescheduling may be carried out more quickly using automated systems instead of manual methods.

### 2.3 The Need for Safety

Evaluating the impact of schedule changes is difficult. Automated scheduling systems provide increased flexibility to manage schedule changes while ensuring health and safety of space systems. Automated systems perform constraint checking and produce various reports such as impact evaluation, schedule statistics, and history logs in order to minimize problems introduced by schedule changes.

### 2.4 Distributed Scheduling Hierarchy

Automated scheduling systems are needed to support remote science users. Instead of depending on a centralized operations control center to operate their instruments, science users may directly control the flight instruments from a university or other home institution. The planning and scheduling capability is no longer centralized in one place; instead, the planning and scheduling capability is distributed between the operations control center and the user sites. Figure 1 and Figure 2 show examples of distributed planning and scheduling architectures.

The system architecture is hierarchical because the operations control center must schedule space-to-ground communications support with the Network Control Center (NCC). Planning and scheduling systems exist at the NCC, the operations control center, and the customer sites. With such a complex architecture, automated scheduling becomes mandatory.

Figure 1 illustrates the planning and scheduling hierarchy that currently exists. The network level (level 1) contains the NCC and the Flight Dynamics Facility (FDF). The NCC is the control center that schedules communication services for spacecraft that use the Tracking and Data Relay Satellite System (TDRSS). The FDF provides orbit, attitude, and navigation products used for generating mission plans and schedules. At the platform level (level 2), spacecraft are controlled and managed by Payload Operations Control Centers (POCC) or Mission Operations Control Centers (MOCC). Presently, at the payload level (level 3), the Space Shuttle may contain Spacelab payloads managed by the Spacelab POCC.

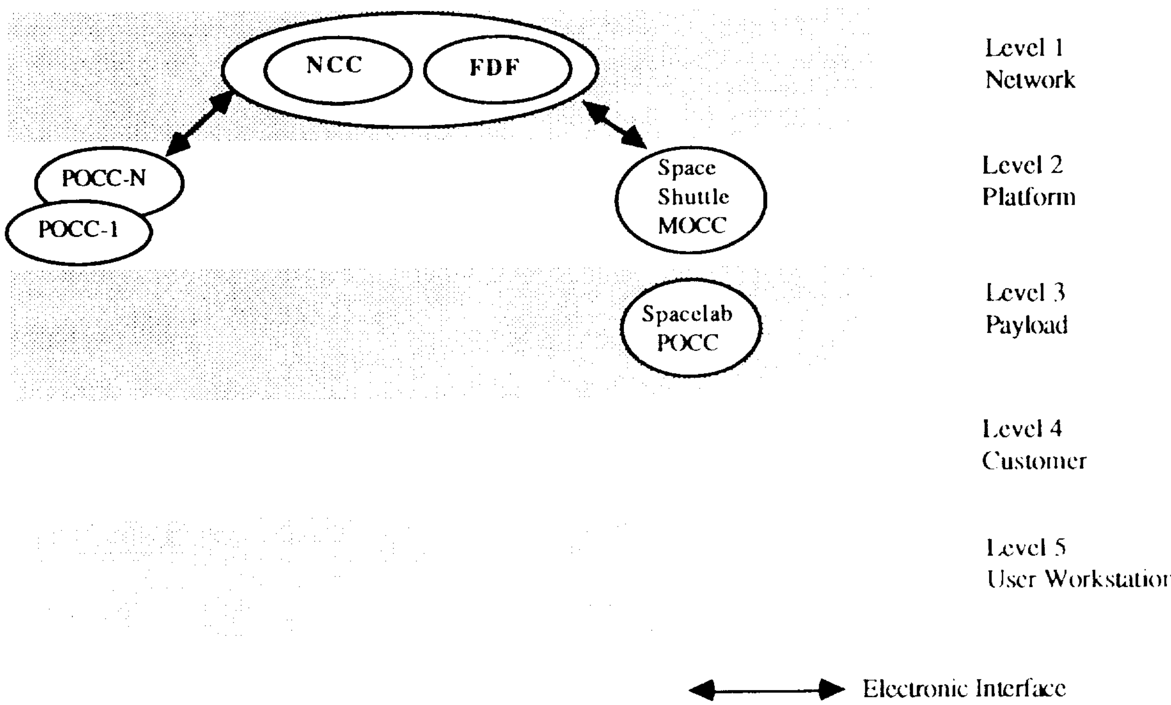


Figure 1. Current Planning and Scheduling Hierarchy

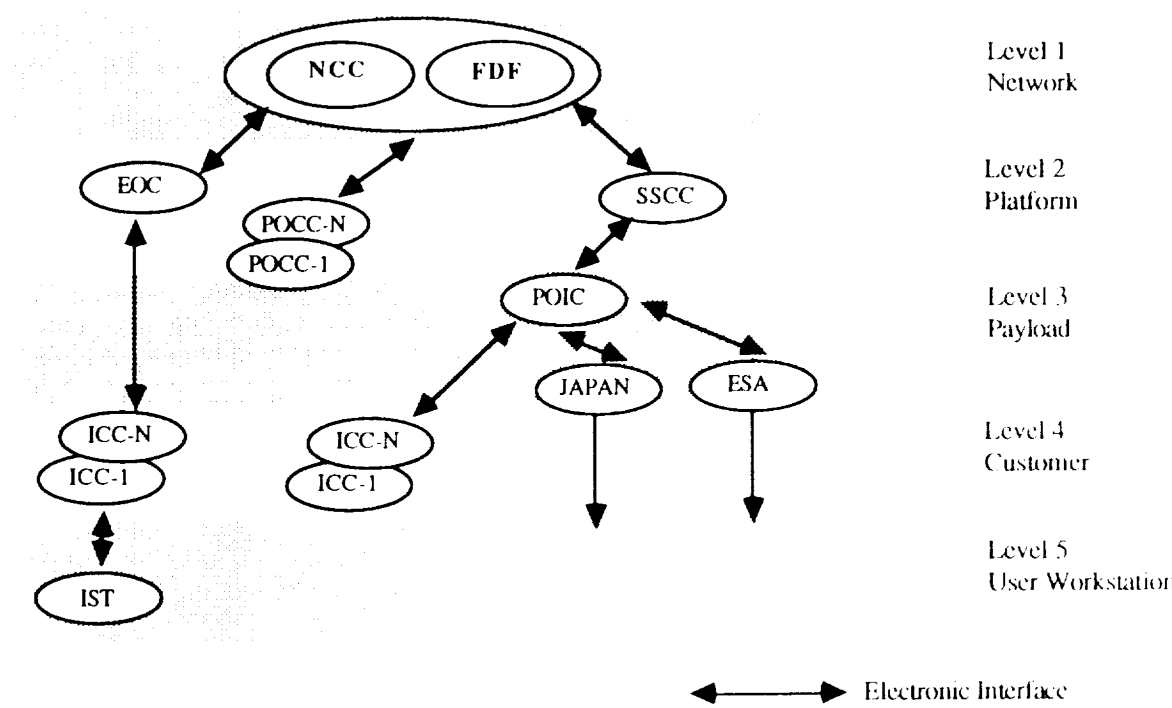


Figure 2. Freedom Era Planning and Scheduling Hierarchy

The Space Station Freedom environment is an example of a complex, distributed, hierarchical planning and scheduling network. For the Freedom era, the planning and scheduling process will be more automated and distributed in a hierarchy containing additional levels and elements at each level.

Figure 2 illustrates the planning and scheduling hierarchy for the Freedom era. With additional levels and elements, the Freedom era hierarchy is more complex than the current hierarchy. The network level (level 1) is similar to the current configuration. The platform level (level 2) includes the Earth Observing System Operations Center (EOC), the Space Station Control Center (SSCC), and POCCs for various spacecraft. At the payload level (level 3), the Payload Operations Integration Center (POIC) at Marshall Space Flight Center (MSFC) coordinates activities among the international partners [i.e., Japan and the European Space Agency (ESA)] and many Instrument Control Centers (ICC) for use of the manned base resources. The customer level (level 4) includes the principal investigators and the ICCs for the instruments. The ICCs may support guest investigators and co-investigators who use remote user workstations or Instrument Support Terminals (IST) (level 5) to communicate with an ICC.

## 3 The Mission Planning Process

Figure 3 shows a mission planning process. Strategic mission goals are developed at the beginning of a mission. During routine operations, a repetitive planning process occurs, typically on a weekly cycle. Investigators and coinvestigators generate plans for instrument operations. Specific resource availability profiles may not be known due to security rules or the commercial proprietary nature of certain payloads.

While investigators are generating instrument plans, spacecraft operations personnel are generating plans for maintaining the health and safety of the satellite. These plans include operations such as tape recorder dumps, command loads, and orbit adjustments.

Typically a week or two prior to schedule execution, plans from the investigators are integrated with spacecraft operations plans, and then schedules are produced. Schedules are analyzed by scheduling personnel to verify that mission goals are being met. If the schedule does not adequately meet the mission goals, it can potentially be improved by using the flexibilities specified in the plans (relaxing resource requirements or scheduling alternative activities, for example). In distributed environments, scheduling personnel may request additional resources from other scheduling sites. After the schedules are produced, they are sent to the investigators. If schedules are not satisfactory, investigators may submit altered plans.

## 4 The FERN Language

In an automated scheduling system, users need to express plans for operations in a format that computers can interpret. In general, defining requirements is not simple, whether the requirements describe software functionality, hardware capability, or as in our application, user instrument operations plans and resource requirements that support science experiments and flight operations. User resource requirements may be complex because user activities are diverse, flexible, and changeable. Their activities may be related to constraints, orbital events, and other activities. A better mechanism is needed to represent this information.

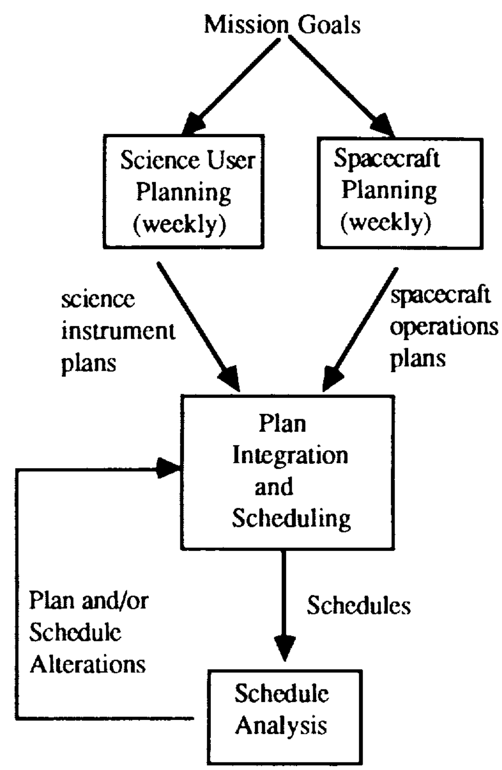


Figure 3. The Mission Planning Process

Since people use languages to communicate, we propose that user plans be represented in a language format that computers can process. A language format is needed to express the flexibilities and alternatives contained in the instrument plans. This method is more expressive than using data structures such as arrays, records, and tables. We use a language format called FERN (Flexible Envelope Request Notation).

FERN has proven to be a general scheduling language. It has been used to represent Solar Mesosphere Explorer (SME) requests, Upper Atmosphere Research Satellite (UARS) requests, and NCC requests.

In many scheduling environments currently in operation, conflicts are often resolved manually. Sometimes users meet to resolve conflicts; however, with increased security restrictions due to DOD and commercial payloads, this form of conflict resolution might no longer be permitted. FERN provides the flexibility that allows an automated scheduling system and project operations personnel to resolve conflicts without violating security restrictions and rules.

FERN supports expressing scheduling requirements at different levels of abstraction. Detailed resource requirements are specified at the lowest level in steps. Resource usage within a given step is constant over the duration of the step while the duration is often variable. Steps can be grouped together into activities. In an operational environment, steps would be defined at the beginning of a mission and then grouped into meaningful activities. Future planning would be done using mnemonic activity names without the need to recalculate detailed step requirements. A pattern of repetition for activities can be specified in a generic request. A generic request can succinctly represent a plan for recurring operations. Each generic request is assigned a priority by the user, which indicates its importance relative to other requests by the same user. Temporal constraints can be specified between steps or between activities. Figure 4 shows the organization of information within generic requests, activities, and steps.

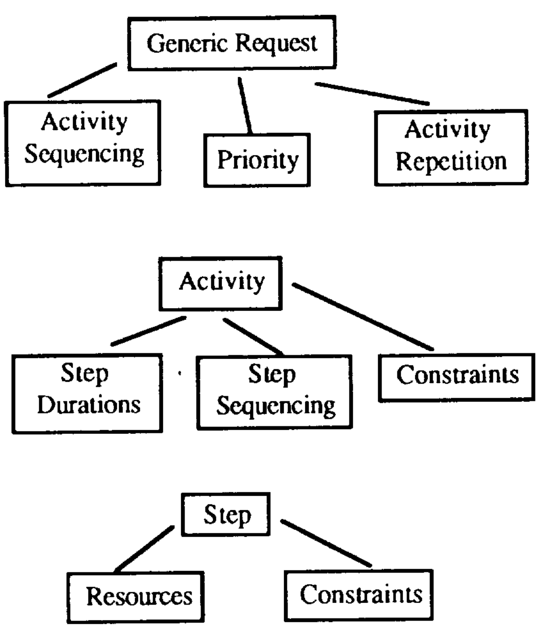


Figure 4. Information Contained in Steps, Activities, and Generic Requests

The following sections describe in more detail some of the specific features of FERN. For each requirement in an activity (a resource requirement or a temporal constraint), the user may specify a relaxation level ranking from 1 to 10. If a schedule is generated that is not consistent with mission goals, scheduling personnel may successively relax requirements as specified to attempt to improve the schedule. Requirements with a ranking of 1 are relaxed first. If no relaxation level is specified, the requirement cannot be relaxed.

### 4.1 Resource Flexibilities

FERN allows resource amounts to be specified at different relaxation levels. For example, a power requirement can be specified with two relaxation levels as follows:

POWER (300 watts
    AND 250 watts AT RELAXATION 2
    AND 150 watts AT RELAXATION 6)

In this example, if 300 watts of power is not available, the scheduling system tries to schedule the request at 250 watts and then 150 watts. Requirements with relaxation levels 3, 4, and 5 are relaxed before the power requirement is relaxed from 250 watts to 150 watts.

With no specified relaxation, the example becomes:

POWER 300 watts.

### 4.2 Temporal Expressions

We use the term "interval" to represent a window in time with a specific start and end time and the term "interval set" to represent a collection of nonoverlapping intervals. Temporal expressions allow users to create new interval sets as functions of predefined interval sets and give names to them such as "weekday" and "spacecraft night." Users may define new interval sets by applying the UNION, INTERSECT, MODIFY, and SELECT operators to existing interval sets.

The UNION and INTERSECT operations are set operators. For example, given a temporal interval such as "Wednesday" representing a particular 24-hour period and an interval set such as "afternoon", which contains the time period from 1 p.m. to 4 p.m. every afternoon during a week, an interval representing "Wednesday afternoon" could be defined by intersecting "Wednesday" and "afternoon".

The MODIFY operation is useful for changing the start and end times of an existing interval. For example, to create an interval that lasts from 2 p.m. to 3 p.m. using the pre-defined interval above, specify:

MODIFY Wednesday-afternoon
    WITH START LATER by 1 hour
    WITH END EARLIER by 1 hour

The SELECT operator allows specific windows (intervals) within an interval set to be "selected". For example, to "select" the second and fourth afternoons from the "afternoon" interval set, specify the following:

SELECT afternoon (2, 4)

Temporal expressions are an important tool that enables users to work with their own terminology.

### 4.3 Temporal Constraints

Once a temporal interval such as "Wednesday-afternoon" is defined it can be used within a temporal constraint. For instance:

activity x DURING wednesday-afternoon.

FERN contains a general temporal constraint facility for expressing indefinite interval relations and the thirteen simple interval relations as described in [Vilian and Kautz, 1986]. Temporal relationships can be specified between two activities or steps. One form of a constraint construct is:

```
Request x
  [STARTS | ENDS]
   [MORE THAN | LESS THAN | EXACTLY]
     <duration>
      [BEFORE | AFTER]
        [<activity>| <step>].
```

For example,

Request X starts more than 5 minutes before Request Y.

Simple interval relations such as "before" and "after" are expressed in a similiar English-like syntax.

### 4.4 Alternative Activities

Alternative requests allow users to request an entirely different activity if the resource scheduling algorithm cannot accommodate the initial request. Users want to propose alternative experiments if their initial plans cannot be supported.

### 4.5 A Generic Request Example

To illustrate the hierarchy of the generic request capability, a sample set of FERN definitions is shown below. Upper Atmospheric Research Satellite (UARS) contains 10 scientific instruments. One of these instruments is the Improved Stratospheric and Mesospheric Sounder (ISAMS) which has a 100 percent duty cycle viewing the Earth's atmosphere limb. There are separate instrument modes for spacecraft day and night. This example only uses some of the expressive capabilities of the language, but it shows the ability of generic requests to generate many schedule activities over an indefinite period of time:

```
Generic ISAMS_NORMAL_GEN is
  1 ACTIVITY PER UARS_Orbit
  SCHEDULE
    ISAMS_Normal_Act
END GENERIC
```

This example of a generic request definition is straightforward. One occurrence of the activity ISAMS_Normal_Act is to be scheduled every UARS orbit. The activity may turn out to be simple or complex. The activity definition is shown below.

```
ACTIVITY ISAMS_Normal_Act is
  STEP
    ISAMS_Daytime_View_Step
            FOR AS LONG AS POSSIBLE,
    ISAMS_Nighttime_View_Step
            FOR AS LONG AS POSSIBLE
END ACTIVITY
```

This example shows that the activity is made of two parts (steps). The first step occurs when the spacecraft is in daylight, and the second step occurs during spacecraft night. The activity definition includes the step durations. A duration of "for as long as possible" needs a constraining time interval. In this case, the constraint is indicated in the step definition:

```
STEP ISAMS_Daytime_View_Step is
  RESOURCES
    ISAMS,
    UARS_Power     14 watts
  CONSTRAINT
    Occurs Entirely During UARS_Daytime
END STEP
```

```
STEP ISAMS_Nighttime_View_Step is
  RESOURCES
    ISAMS,
    UARS_Power     14 watts
  CONSTRAINT
    Occurs Entirely During UARS_Nighttime
END STEP
```

Steps contain the resource allocations that support the activity. In addition, steps may have constraints that restrict time periods when they can be scheduled. The ISAMS_Daytime_View_Step can only occur during the time period defined as UARS_Daytime. ISAMS_Nighttime_View_Step can only occur during UARS_Nighttime. These constraints restrict the actual starting and ending times for the steps. If other requested resources such as UARS_Power are available during the appropriate time periods, the steps are scheduled for the entire duration of the time period UARS_Daytime and/or UARS_Nighttime.

Note that some additional definitions must exist in order to process the above FERN requests. Resource availabilities for ISAMS and UARS_Power must be defined. Time periods for UARS_Orbit, UARS_Daytime, and UARS_Nighttime must also be defined. Since the ISAMS often performs the same science information gathering experiments, these requests can be used repeatedly as needed.

## 5 The Request-Oriented Scheduling Engine (ROSE)

ROSE is currently under development as a scheduling tool to demonstrate automated scheduling and distributed scheduling concepts. The current major capabilities of

ROSE are as follows: (1) to receive scheduling messages via a file transfer protocol from any scheduler or user located on the host network and respond with appropriate scheduling messages, (2) to create an initial schedule from user requests, and (3) to reschedule (as needed) to satisfy mission goals.

ROSE was originally implemented on a Texas Instruments Explorer and has been ported to the Symbolics 36xx environment under Symbolics OS Release 6.1 and Genera 7. The system is currently being ported to Ada in a VMS 5.1 environment using X-windows. Since we anticipate a port to a UNIX Sun/3 environment we are avoiding using any features that would make this port difficult, such as VMS system services, implementation-dependent language features, and implementation-dependent X tool kits.

### 5.1 Communications Capabilities

ROSE supports interscheduler communication through the transmission of resource requests and schedules. Users transmit requests expressed in the FERN language to ROSE. The user receives two responses from ROSE. The first is an acknowledgement message that confirms receipt of the message. This message indicates whether errors were detected by the FERN parser. When all requests are received, a schedule is created. The second response ROSE sends is schedule messages indicating the name of scheduled requests, the time assigned to the request, and the resource levels dedicated to the request. Users receive a schedule message for each request sent to ROSE, but are not informed of the disposition of requests from other users.

### 5.2 Scheduling Capabilities

The ROSE system creates an initial schedule from a set of requests, resources, and interactively-specified scheduling heuristics. ROSE currently schedules activities at the rate of approximately 900 activities per hour on a 1 MIP VAX workstation for schedules with 1000 - 2000 requests. The ROSE operator chooses a *selection heuristic* and a *placement heuristic* from predefined menus. The selection heuristic evaluates each activity and determines which activity should be scheduled next based on priorities, resource consumption, and an estimation of the restrictiveness of an activity's temporal constraints. The placement heuristic uses activity preferences and information about the existing schedule to determine the placement of the activity. The ROSE operator can create many different alternative schedules by selecting different combinations of selection and placement heuristics. Alternative schedules can be compared and evaluated with respect to mission goals. ROSE always creates conflict-free schedules. Manual scheduling is also supported through the graphical interface.

### 5.3 Rescheduling Capabilities

In a resource constrained environment, resource conflicts will occur, and rescheduling will usually be a necessary step after the initial schedule is created. A simple approach for scheduling is to resolve resource conflicts by choosing the higher priority activity. In a network of ROSE schedulers, each allowing flexible requests, there are several options:

- *Overbook the resource.* In our distributed scheduling environment, overbooking is a viable conflict resolution scheme since additional resources can potentially be acquired from another scheduler.

- *Relax this activity.* A minor adjustment to the scheduling requirements of the request might make it possible to schedule it.

- *Relax other activities.* Higher priority activities might have their requirements relaxed in order to accommodate lower priority activities.

- *Acquire additional resources.* In a network of schedulers, it might be desirable to request and obtain resources from another scheduler.

- *Manually add the activity.* ROSE provides operator displays and tools that support the interactive rescheduling of existing activities.

- *Use the automated Schedule Enhancement Technique.* ROSE provides an automated heuristic search capability similar to a best-first search. This technique has proven useful in enhancing existing schedules. The search proceeds by looking for times on the schedule when an activity can almost be scheduled. The algorithm then finds those activities that need to be deleted to make it possible to schedule the activity, and then reschedules the deleted activities. This technique is described in more detail in [Odubiyi and Zoch, 1989].

- *Choose the higher priority activity.* As a last resort, some activities are not scheduled.

- *Use any combination of the above capabilities*-- An operator can mix and combine these techniques as needed to improve the current schedule.

An operator may reschedule activities to improve a schedule, to cope with equipment failures, or to accommodate changes in plans. The operator is faced with an overwhelming amount of information. An interactive interface must effectively organize, filter, and display this information at the appropriate level of detail to aid an operator in making informed scheduling decisions. ROSE aids an operator in analyzing and comparing existing schedules and in making modifications to improve a schedule, respond to changes in resource profiles (equipment failures), or respond to new user requests. These features have proven to be a valuable aid in assessing the situation and modifying existing schedules.

### 5.4 ROSE User Interface

Figure 5 shows the ROSE interface. The three main windows are the Distributed Scheduling Network Window, the Real-Time Message Monitoring Window, and the Timeline of Scheduled Requests Window.

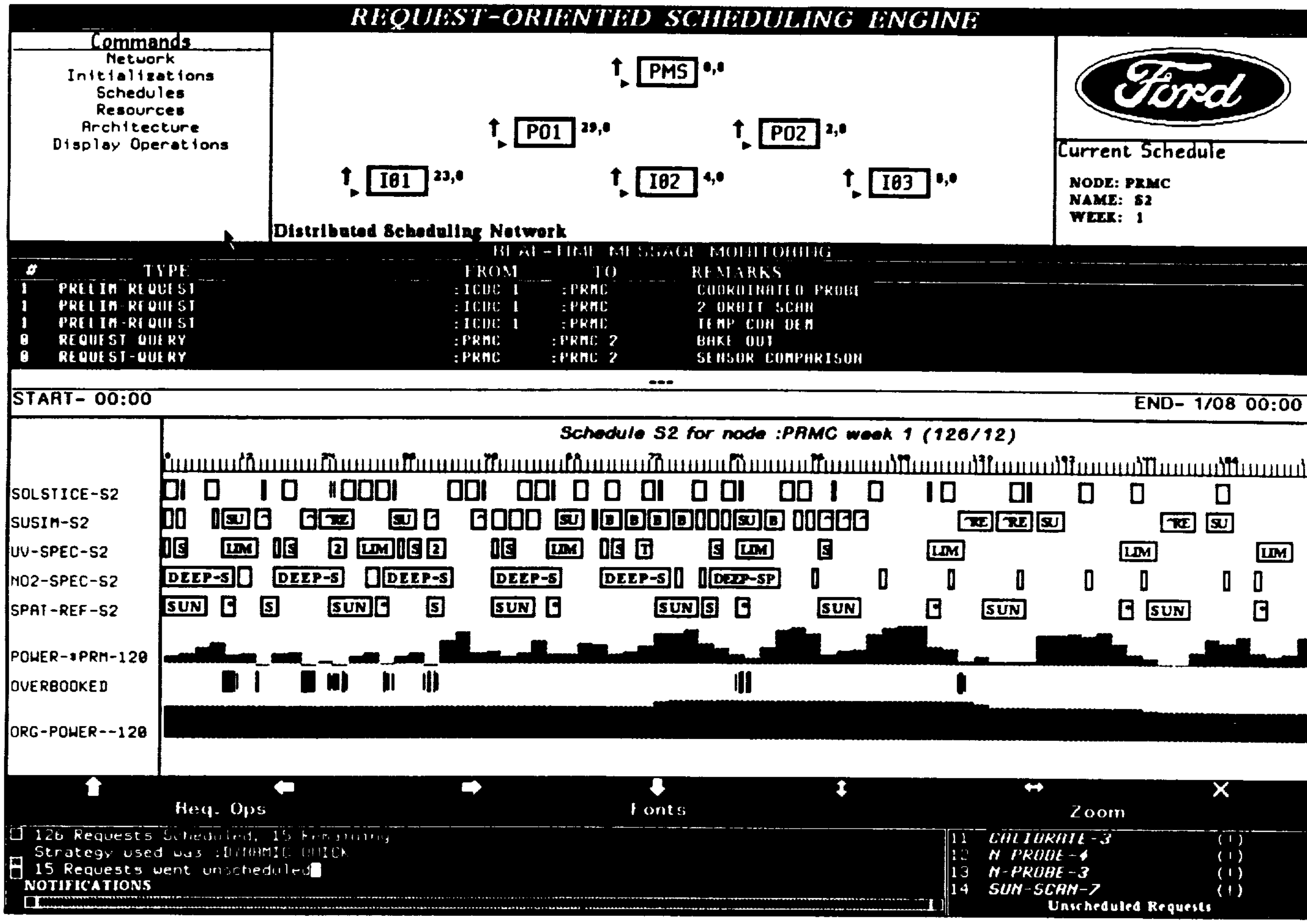


Figure 5. ROSE Interface with Sample Schedule and Resource Plots

The Distributed Scheduling Network Window displays the scheduling network and the message traffic within the network. Each rectangle represents either a NASA scheduling facility such as a Payload Operations Control Center (POCC) or a user Instrument Control Center (ICC). Figure 5 shows a simplified scheduling network for Space Station Freedom. The Platform Management System (PMS) makes block allocations of resources to scheduling centers P01 and P02. Scheduling requests are sent from the Instrument Control Centers (I01, I02 and I03) to scheduling facilities P01 and P02 where schedules are created. Users at I01, I02 and I03 are then sent scheduling messages that tell them where their requests were scheduled and the amount of resources that were allocated.

The middle portion of the screen is the Real-Time Message Monitoring Window. This window displays the names of scheduling messages received by this scheduler from other schedulers in the network. The user can click on these message names to view the details of these messages.

The lower portion of the screen displays the Timeline of Scheduled Requests Window. Schedules are currently one week in duration. Each time line shows the requests scheduled for a particular user instrument. Multiple schedules may be created using different scheduling heuristics. Once created, an operator can rearrange these time lines so that the different schedules can be compared. The operator can also perform standard window manipulations such as panning and zooming on any part of the time line. The Timeline of Scheduled Requests Window, in conjunction with the Unscheduled Request Window, provides an object-oriented graphics interface to all requests. Every request can be viewed, edited, relaxed, scheduled, or unscheduled.

The Timeline of Scheduled Requests Window is also used to display resource plots. Resource profiles can be obtained for original resource amounts, remaining resource amounts, and resource amounts used by a particular ICC.

During the scheduling process, a ROSE user can set an overbooking limit for each resource. This option is useful for investigating the effects of having additional resources. The scheduler will treat these extra amounts of resources as if they were actually present. As shown in Figure 5, ROSE can display a time line showing where over booked amounts are actually utilized. Clicking the mouse on a rectangle on this time line generates a display showing which resources are overbooked at that time.

Figure 6 shows the ROSE interface displaying the results of a *draw available start times* operation. This display gives the operator a complete understanding of why a request could not be scheduled. A time line is displayed for each resource requirement or temporal constraint in the request. The dark areas on the time line show where the particular requirement is satisfied. The top time line, labeled INTERSECTION, displays the intersection of all the other time lines. It shows the places where the request can be scheduled. As shown in Figure 6, the *draw available start times* display contains a time line for the following:

- Every resource or environmental constraint used by the request (POWER, COM-LINK, TAPE-RECORDER, VIBRATION, and NO2-SPEC). The dark areas show places on the time line where sufficient resources are available to meet the needs of this request.

- Each temporal constraint (labeled 1 and 2). The dark areas show places where the temporal constraint is satisfied.

- The DIRECTION constraint (labeled DIRECT). This is a special type of temporal constraint.

Two summary time lines are also shown, labeled DYNAMIC and TEMPORAL. The DYNAMIC time line shows where a request can be scheduled based on its required positioning with respect to other requests. The TEMPORAL time line displays the intersection of all temporal constraints and the special DIRECTION constraint for the request.

The *draw available start times* display identifies the schedule conflict areas. For example, the N-PROBE-3 request has a DIRECTION constraint that is restricting the scheduling of this request to a short period early in the schedule. The NO$_2$-spectrometer instrument is busy during the early part of the week, making it impossible to schedule the request. Other resources such as POWER and TAPE-RECORDERS are abundant.

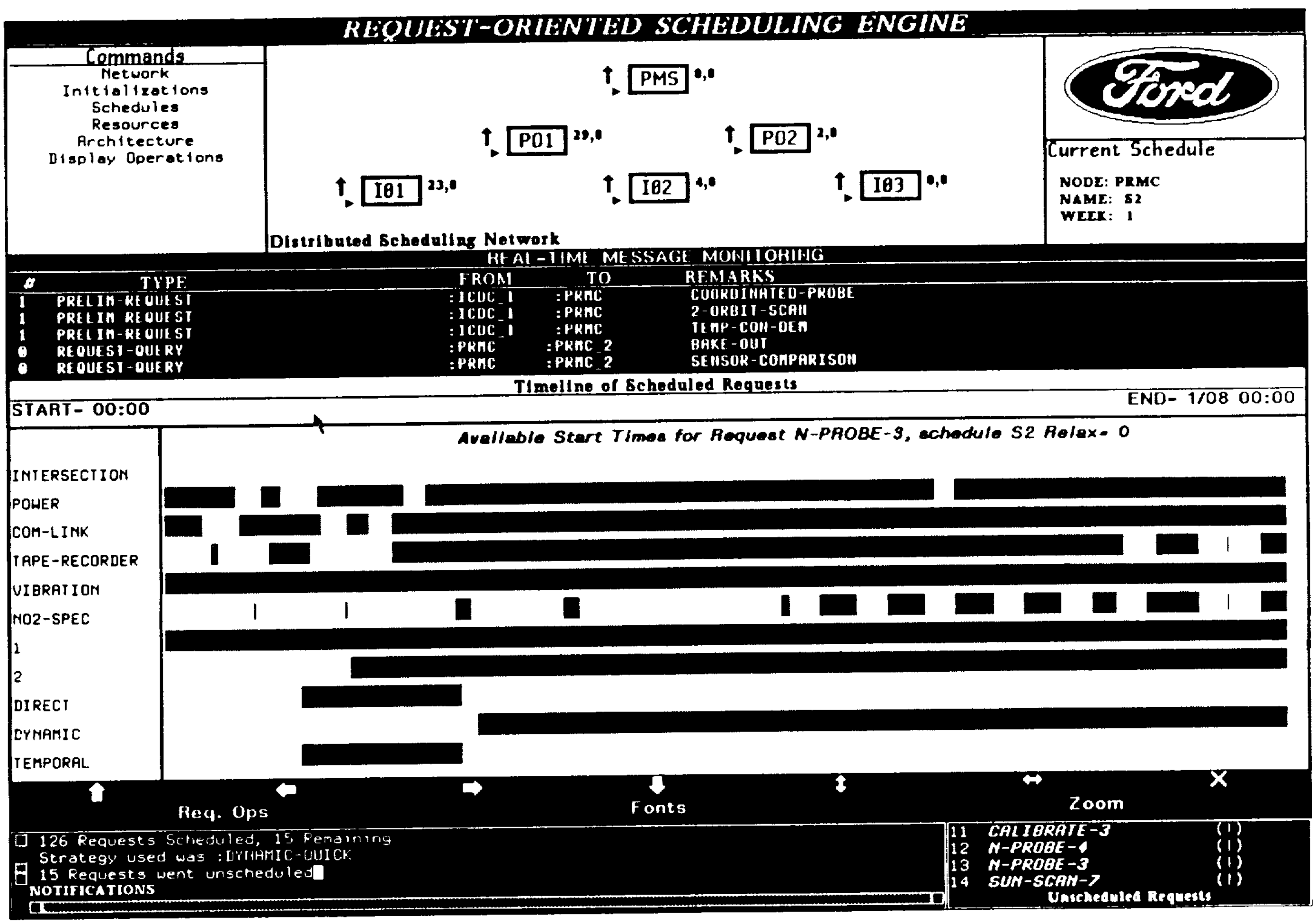


Figure 6. ROSE Interface with Display of Available Start Times for Request N-PROBE-3

## 6 Conclusion

We have addressed a difficult aspect of mission planning and scheduling--representing the available flexibilities in plans to aid in the automation of the scheduling process and reduce replanning. The increased automation is necessary to support increasingly complex future NASA missions.

The FERN planning language is designed to be robust, readable, flexible, and object-oriented. FERN supports a variety of user resource requirements and constraints. It supports alternative plans and repetitive activities that are based on temporal expressions (user-defined time periods) rather than specific start times. The language contains hierarchical constructs that support data abstraction and reusable data objects.

## References

[Gaspin, 1989] Christine Gaspin. *Mission Scheduling.* Proceedings of the 1989 Goddard Conference on Space Applications of Artificial Intelligence

[Berner, *et al.*, 1989] Carol A. Berner, Ralph Durham, and Norman B. Reilly. *Ground Data Systems Resource Allocation Process.* Proceedings of the 1989 Goddard Conference on Space Applications of Artificial Intelligence

[Reddy, 1989] Surrender Reddy. *Generic Approach to Developing Scheduling Systems.* Computer Sciences Corporation, Beltsville, MD, Document number CSC/TM--89/6106. Prepared for GSFC under contract NAS 5-31500

[Sponsler and Johnston, 1990] Jeffrey L. Sponsler and Mark D. Johnston. *An Approach to Rescheduling Activities Based on Determination of Priority and Disruptivity.* Proceedings of the 1990 Goddard Conference on Space Applications of Artificial Intelligence

[Odubiyi and Zoch, 1989] Jide' Odubiyi and David Zoch. *A Heuristic Approach to Incremental and Reactive Scheduling.* Proceedings of the 1989 Goddard Conference on Space Applications of Artificial Intelligence

[Vilian and Kautz, 1986] Marc Vilian and Henry Kautz. *Propagation Algorithms for Temporal Reasoning.* Proceedings of the Fifth National Conference on Artificial Intelligence

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# Intelligent Perturbation Algorithms for Space Scheduling Optimization

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**Abstract** - The limited availability and high cost of crew time and scarce resources make optimization of space operations critical. Advances in computer technology coupled with new iterative search techniques permit the near optimization of complex scheduling problems that were previously considered computationally intractable. This paper describes a class of search techniques called Intelligent Perturbation Algorithms. Several scheduling systems which use these algorithms to optimize the scheduling of space crew, payload and resource operations are also discussed.

## Using Heuristics for Optimization

The development of techniques to solve scheduling problems has historically centered around the investigation of idealized scheduling models which were often simpler than problems typically encountered in the real world.[4, 6, 13] Except for the simplest models, scheduling problems can be described mathematically as "NP-Hard."[3, 14] All known mathematical techniques for finding optimal solutions to NP-Hard problems are too slow to solve realistically large problems.[15]

In practical applications, heuristic techniques are often used to solve problems which are otherwise intractable. Heuristics usually produce solutions of good quality but do not always find the most optimal solution. Whereas the computational difficulty of finding the exact optimum solution increases exponentially as a function of the size of an NP-Hard scheduling problem, with heuristic algorithms the difficultly of finding "quasi-optimal" solutions usually increases only in a polynomial fashion. Polynomial heuristic algorithms can therefore find solutions to realistic problems in a computationally feasible search time.

In some cases, heuristic techniques can be shown to produce solutions which have desirable properties such as guaranteeing to always be within a certain percent of the optimal solution. For more complicated problems, however, even these guarantees may not be possible. In the case of many space related scheduling problems, the optimization criteria can be inexact and the data base (e.g., estimates of the expected time necessary to complete an activity) may be uncertain; hence, a heuristic can be considered successful if it can be applied to a set of test problems and shown to consistently produce schedules which are nearly optimal. With confidence in such a heuristic it could then be applied to larger and more complicated problems for which finding the optimum is not realistic. Additionally, having a heuristic which can compute a solution on a time scale fast enough for the solution to be used immediately (as would be necessary to perform real-time replanning) is superior to producing a nominally better solution which cannot be obtained in real time.

## Intelligent Perturbation Algorithms

A typical scheduling problem involves the placing of activities onto a timeline while respecting constraints which may restrict the times at which the activities many be performed and the resources available for the activities to use. A grading function is established to judge the relative merits of different schedules.

Intelligent Perturbation Algorithms are heuristic techniques that have been developed by the author for the quasi-optimization of complex scheduling problems. These algorithms iteratively search the combinatoric solution space just as techniques such as gradient search are used for solving continuous domain optimization problems. Like other iterative search techniques such as Simulated Annealing Algorithms[1,5,7,16] and Genetic Algorithms[17,18], Intelligent Perturbation Algorithms iteratively examine (and make perturbations upon) successive schedules in an attempt to find a progressively better solution. Unlike these other techniques (which search in a more random fashion), Intelligent Perturbation Algorithms use a strategy that considers both the structure of the problem's constraints and its objective function to decide how to modify a schedule to increase the likelihood that the next perturbation will yield a more optimal solution.

To create an initial schedule (the first iteration), a method is devised to generate a ranking of all unscheduled activities, and then the highest ranked activity is added to the timeline. The procedure is then repeated to select the activity with the next highest ranking, adding it to the timeline. This continues until all the activities (or as many as possible) have been added to the schedule. The particular method used to initially rank the activities and the specific way in which activities are added to the timeline are not pertinent to the general operation of the Intelligent Perturbation Algorithm.

Following this first iteration, the rankings of the activities are adjusted using a problem specific procedure called a perturbation operator. These new rankings are then used on the next iteration to produce another schedule which is hopefully of superior quality (as measured by the grading function). This process then repeats for subsequent iterations until a cutoff criteria is reached. The best schedule found during the course of the search is then recalled.

Emperical experience has shown that good perturbation operators share many characteristics:

1) The operator should increase the rankings of an activity or activities which were not satisfactorily scheduled during the previous iteration. The operator should also increase the rankings of "bottleneck" activities (which may have been successfully scheduled) that prohibited the satisfactory scheduling of other activities due to temporal constraints linking those activities to the bottleneck activity.

2) The operator should be able to potentially span the search space in a small number of steps.

3) The computational overhead of computing the perturbations between each iteration should be small compared to the computational cost of producing a single schedule. Extensive testing has shown that by looking at many good schedules, Intelligent Perturbation Algorithms are likely to find a very good schedule in a reasonable number of iterations. There is a greater payoff in searching through more schedules than in investing a great deal of computation in the perturbation operator. This is consistent which the strategy employed by the best chess playing computer programs which achieve their skill by searching through a large number of positions rather than through the use of strategy.

4) The perturbation operator should have a random component (or some other provisions) for avoiding loops and getting trapped near local optima.

For many space operations, the costs of opportunities which are lost due to inefficient scheduling can easily amount to millions of dollars per week. The proper design of the perturbation operator is critical to the success of the Intelligent Perturbation Algorithm, and will vary for different types of scheduling problems. The specific details can be considered proprietary; as the utilization of space becomes more commercial, the possession of good perturbation operators can provide a capability to operate more efficiently and thereby bestow a competitive advantage.

Intelligent Perturbation Algorithms can be made flexible enough to accommodate a large range of problem structures including highly complicated constraint environments which could not be addressed by previous heuristic optimization methods. The search inherently focuses on the complicated parts of a scheduling problem while it avoids dealing with factors which are not present in a particular problem instance.

Figure 1 shows results of using the Intelligent Perturbation Algorithm, averaged over many test problems.[10] In each problem, the objective was to generate a timeline which allowed completion of a set of time and resource-constrained activities as early as possible. Using non-iterative heuristic techniques standard in operations research literature, solutions were found which averaged about 23% longer than optimal; after 10 search steps using an Intelligent Perturbation Algorithm, average schedule quality was improved to within 10% of the optimum, a significant improvement. After 100 search steps, the average schedule quality was improved to only 7% longer than the optimum. Usage on many different problems has shown that while the scaling of the axes will vary for different types of scheduling problems, the general character of the "learning curve" relating schedule quality to the number of iterations remains largely unchanged.

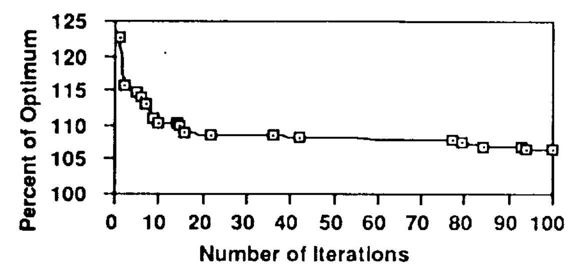


Figure 1: Solution Improvement with Iteration Number

**Intelligent Perturbation Algorithm Applications**

Aerospace systems have been developed which apply Intelligent Perturbation techniques to the scheduling of crew, payloads, and resources aboard space-based systems. Space Industries is examining the application of Intelligent Perturbation Algorithms beyond the aerospace industry into diverse areas such as the optimization of petrochemical plant operations and the scheduling of medical operating rooms. Additionally, an independently developed iterative refinement methodology, called chronology-directed search, has been developed at JPL and is being applied to the scheduling of deep space missions.[2]

**Space Station Scheduling**

Aboard the International Space Station *Freedom*, crewmembers would benefit from having the capability to participate in the scheduling of their own activities. To address this need a prototype interactive software tool known as the MFIVE Space Station Crew Activity Scheduler and Stowage Logistics Clerk was developed at the Space Systems Laboratory of the Massachusetts Institute of Technology (MIT).[10, 11, 12] MFIVE (Figure 2) provides a user friendly interface for building, solving and displaying scheduling problems as well as for investigating the features which will be necessary to provide a real-time scheduler for use aboard *Freedom*.

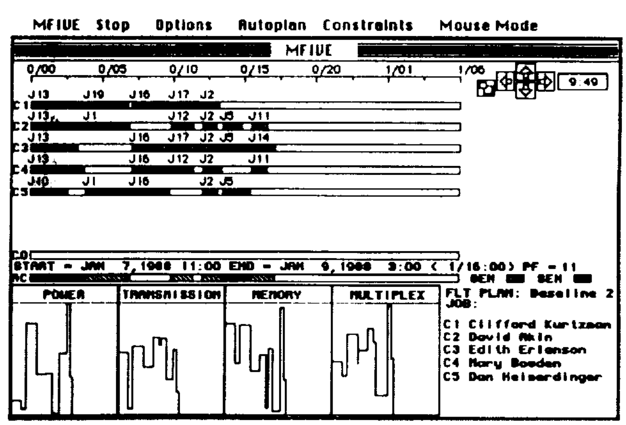


Figure 2: MFIVE Space Station Scheduling Worksheet Showing Task Assignment and Resource Usage for Five Crewmembers

MFIVE was not intended to provide a fully robust model of the realistic Space Station environment but rather to demonstrate some of the features which will be necessary to support development of actual Space Station planning and scheduling tools. While the MFIVE system was created to deal primarily with manned activities, it is also capable of dealing with unmanned operations. First prototyped in 1986, MFIVE was used to develop and test the initial implementations of the Intelligent Perturbation Algorithm. MFIVE also demonstrated user-friendly features such as graphics, windows, menus and a mouse-driven interface on a low cost Macintosh desktop computer.

MFIVE is currently being used by the MIT Man-Vehicle Laboratory to examine scheduling scenarios for the Spacelab SLS-1 and IML-1 life sciences pre/postflight baseline data collection facility. These data collection sessions provide control data to compare against data collected on-orbit and measure post-mission readjustment to earth's gravity.

Another optimization tool using the Intelligent Perturbation Algorithm has been developed to support work being done for the Space Station Program Support Contract for the scheduling of Space Station Design Reference Missions (DRMs). Scheduling of DRMs involves generating demonstration timelines for Space Station crew and payload operations at selected periods during the lifetime of the Space Station. As shown in Figure 3, schedules have been generated which show significant improvements over schedules produced with standard scheduling tools, both in terms of resource utilization and in the accomplishment of mission priorities.[8] The analysis of this DRM required the scheduling of 422 requested operations of 74 payloads over a two week period. Three resources were considered: crew, power, and the availability of a high quality microgravity environment. Assuming a rate of $100,000 per IVA crew-hour (as called out by NASA in its recent request for proposals for the Commercial Middeck Augmentation Module), the optimization analysis saved 5.3 million dollars per week in opportunity costs that would have otherwise been lost through inefficient scheduling.

| DRM 4 - Command & Control Zone Operations/Man-Tended Free Flyer Servicing | Payload Runs | Crew-Hours Scheduled |
|---|---|---|
| Requested | 422 | 539 hr, 10 min (118.1%) |
| Available | N/A | 456 hr, 30 min (100.0%) |
| NASA Provided Baseline | 272 | 333 hr, 35 min ( 73.1%) |
| Space Industries Result | 387 | 440 hr, 10 min ( 96.4%) |

**Figure 3: DRM 4 Resource Utilization Optimization**

### Industrial Space Facility Scheduling

The ability to provide flexible manifesting and scheduling is critical to the operation of the Industrial Space Facility (ISF), a man-tended free-flying space platform being developed by Space Industries for launch in the 1990s. The ISF has been designed to serve as a bridge to the Space Station era, providing a high-power, low-gravity environment for conducting microgravity research. A software tool called the Prototype ISF Experiment Scheduler has demonstrated that efficient and cost-effective operation of the ISF is possible through the use of multi-variable optimization techniques based on the Intelligent Perturbation Algorithm.[9] Figure 4 (next page) shows resource utilization profiles for an optimized 100 day ISF mission. The objective function was based largely on maximization of power utilization.


### Acknowledgements

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### Bibliography


[1] Berman, D., McClure, J.W., "A Comparison of Scheduling Algorithms for Autonomous Management of the Space Station Electric Energy System." AIAA Guidance, Navigation and Control Conference, August 1987. AIAA-87-2467.

[2] Biefeld, E.W., and Cooper, L.P., "Scheduling with Chronology-Directed Search." AIAA-89-3137, AIAA Computers in Aerospace VII Conference, October 3-5, 1989.

[3] Blazewicz, J., Lenstra, J.K., Rinnooy Kan, A.H.G., "Scheduling Subject to Resource Constraints: Classification and Complexity." Stichting Mathematisch Centrum, Amsterdam, Department of Operations Research, August 1980.

[4] Dempster, M.A., Lenstra, J.K., Rinnooy Kan, A.H.G., eds., Deterministic and Stochastic Scheduling. NATO Advanced Study Institutes Series. Series C: Mathematical and Physical Sciences, Vol. 84. D. Reidel, 1982.

[5] Gaspin, C., "Mission Scheduling." N89-26585.

[6] Graham, R.L., Lawler, E.L., Lenstra, J.K., Rinnooy Kan, A.H.G., "Optimization and Approximation in Deterministic Sequencing and Scheduling: A Survey." Ann. Discrete Math., Vol. 5, 1979, pp. 287-326.

[7] Hart, R.J., and Goehring, J., "An Application of Simulated Annealing to Scheduling Army Unit Training." U.S. Army Research Institute for the Behavioral and Social Sciences, Technical Report 727, October 1986.

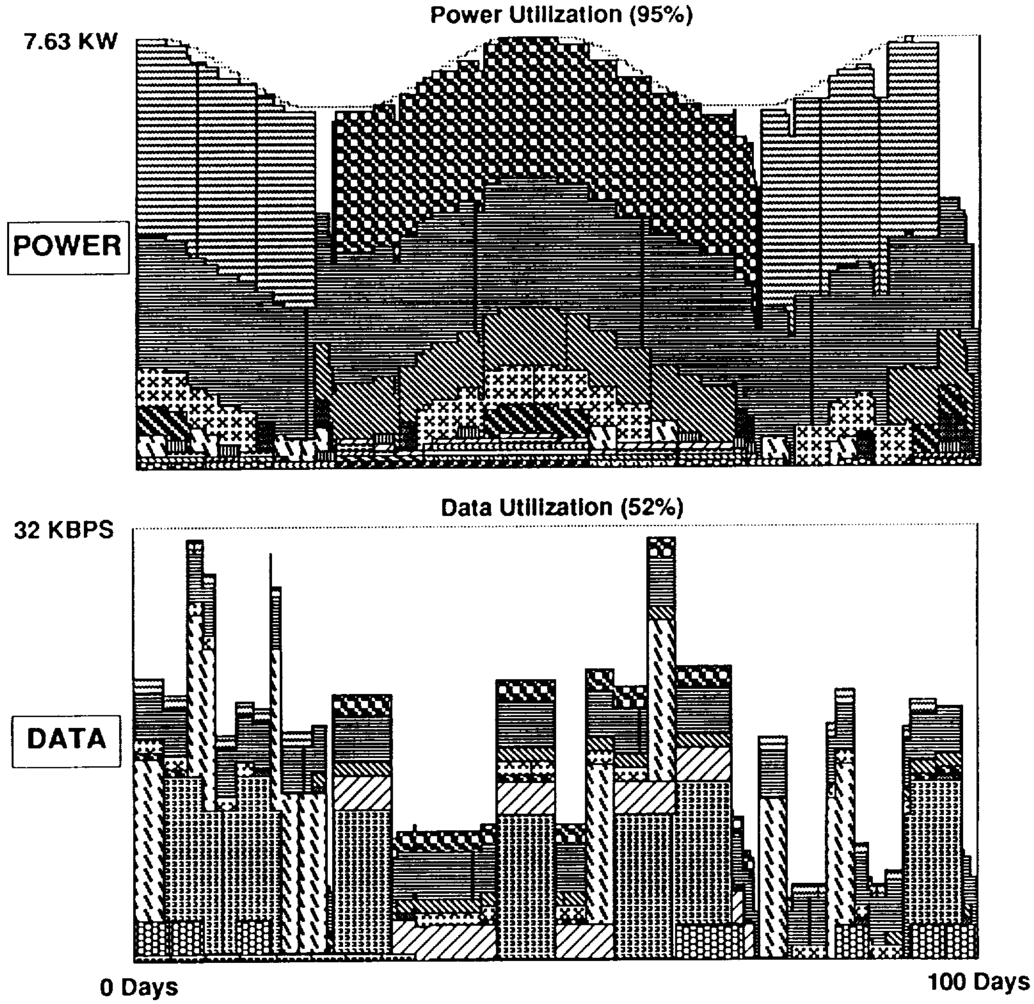
[8] Kurtzman, C.R., Benchmark Services for Space Station Program Support. White Paper, Space Industries International, Inc., July 1990.

[9] Kurtzman, C.R., "Experiment Scheduling for the Industrial Space Facility." AIAA-89-3138, AIAA Computers in Aerospace VII Conference, October 3-5, 1989.

[10] Kurtzman, C.R., Time and Resource Constrained Scheduling, with Applications to Space Station Planning. Ph.D. Thesis, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, Massachusetts, February 1988.

[11] Kurtzman, C.R., and Akin, D.L., "The MFIVE Space Station Crew Activity Scheduler and Stowage Logistics Clerk." AIAA-89-3118, AIAA Computers in Aerospace VII Conference, October 3-5, 1989.

[12] Kurtzman, C.R., Akin, D.L., Kranzler, D., Erlanson, E., Study of Onboard Expert Systems to Augment Space Shuttle and Space Station Autonomy, final report of NASA Grant NAG5-445, July 31, 1986, NASA CR-176958.




| ID # | Experiment Name | Runs Scheduled | Max Runs Requested |
|---|---|---|---|
| 4 | Advanced Automated Directional Solid. Fur. | 4 | 8 |
| 8 | Chemical Vapor Transport - I | 5 | 5 |
| 12 | Diffusive Mixing of Organic Solutions | 1 | 2 |
| 17 | Electrodeposition | 1 | 2 |
| 19 | Electromagnetic Levitator | 7 | 8 |
| 21 | Float Zone Crystal Growth Facility | 1 | 2 |
| 27 | Gradient Furnace for the Get-Away-Special | 8 | 8 |
| 34 | Isothermal Dendritic Growth Experiment | 7 | 8 |
| 41 | Magnetic Isolation System | 5 | 7 |
| 47 | Monodisperse Latex Reactor System | 8 | 8 |
| 49 | Multiple Experiment Processing Facility | 6 | 8 |
| 50 | Non-Linear Optical Monomers | 1 | 3 |
| 51 | Non-Linear Optical Organic Crystals | 1 | 3 |
| 52 | Non-Linear Optical Thin Films | 1 | 3 |
| 53 | Normal Freezing Furnace | 4 | 7 |
| 55 | Organic Separations | 2 | 2 |
| 58 | Physical Vapor Transport of Organic Solids | 8 | 8 |
| 59 | Polymer Microstructure and Morphology | 8 | 8 |
| 65 | Space Ultra-Vacuum Research Facility | 6 | 8 |
| 71 | Reboost | 1 | 1 |
| 72 | Reboost | 1 | 1 |
| Total | | 86 | 110 |

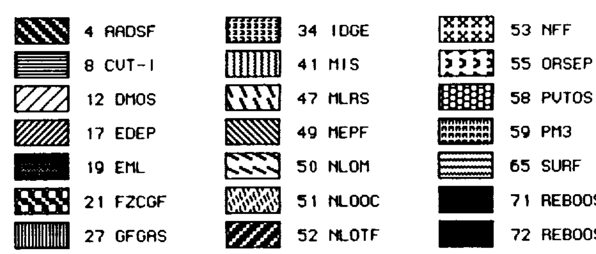



Figure 4: Optimized ISF Schedule


[13] Lawler, E.L., Lenstra, J.K., "Machine Scheduling with Precedence Constraints." Stichting Mathematisch Centrum, Amsterdam, Department of Operations Research, September 1981.

[14] Papadimitriou, C.H., Steiglitz, K., Combinatorial Optimization: Algorithms and Complexity. Prentiss-Hall, Inc., Englewood Cliffs, New Jersey, 1982.

[15] Patterson, J.H., "A Comparison of Exact Approaches for Solving the Multiple Constrained Resource, Project Scheduling Problem." Management Science, Vol. 30, No. 7, July 1984, pp. 854-867.

[16] Price, C.C., and Salama, M.A., "Scheduling of Precedence-Constrained Tasks on Multiprocessors." JPL Invention Report NPO-17219/6725, January 1989.

[17] Sponsler, J.L., "Genetic Algorithms Applied to the Scheduling of the Hubble Space Telescope." N89-26607.

[18] Waltbridge, C.T., "Genetic Algorithms." Technology Review, Vol. 92, No. 1, January 1989.

# Appendix D--Bibliography

# Appendix D—Bibliography


**Conference Introduction**

CTA Incorporated, Planning & Scheduling Lessons Learned Study Executive Summary, June 29, 1990

**Session 1. Concepts for Space Network Resource Allocation**

Hornstein, R., J. Gardner, and J. Willoughby, Distributed Decision-Making for Space Operations: A Programmatic Perspective and A Technical Perspective on Tools and Techniques, AIAA/NASA Second International Symposium on Space Information Systems, Sept. 17, 1990

Information Sciences, Inc., Adaptations to the Traditional Practice of Systems Engineering Management Process: A Guidebook for Project Management, July, 1989

Goddard Space Flight Center, Customer Data Operations System (CDOS) Operations Management Service (COMS) Planning and Scheduling Concept Assessment, by Computer Sciences Corp., May 1990, DSTL-90-010

Wong, Y. and J. Rash, An RF Interference Mitigation Methodology with Potential Applications in Scheduling, Dec. 1990 (paper included in Appendix D)

Wike, J., Automatic Conflict Resolution Issues, Dec. 1990 (paper included in Appendix D)

Geoffroy, A., D. Britt and J. Gohring, The Role of AI Techniques in Scheduling Systems, 1990 Goddard Conference on Space Applications of Artificial Intelligence, May, 1990, NASA CP 3068

Durham, R., N. B. Reilly and J. B Springer, Resource Allocation Planning Helper - RALPH: Lessons Learned, 1990 Goddard Conference on Space Applications of Artificial Intelligence, May, 1990, NASA CP 3068

**Session 2. SNC and User POCC Human-Computer Interface Concepts**

Biefeld, E. and L. Cooper, Operations Mission Planner Final Report, March 15, 1990, JPL Publication 90-16

Goddard Space Flight Center, Design of Planning and Scheduling Interfaces: Guidelines and Display Concepts, by CTA, Inc., Dec. 1990, DSTL-90-027


 PRECEDING PAGE BLANK NOT FILMED

Zoch, D., D. LaVallee, S. Weinstein and G. M. Tong, A Planning Language for Activity Scheduling, Dec. 1990, (paper included in Appendix D)

Goddard Space Flight Center,User's Guide for the Flexible Envelope Request Notation (FERN), by Computer Sciences Corp. and Loral AeroSys, Sept. 1989, DSTL-89-015

Weiland, W., E. Murphy, et al, Computer-Human Interaction Models (CHIMES)-2 System (Revised Report), GSFC Contract NAS-5-30680, Feb. 28, 1991

Thalman, N. and T. Sparn, SURE (Science User Resource Expert): A Science Planning and Scheduling Assistant for a Resource Based Environment, 1990 Goddard Conference on Space Applications of Artificial Intelligence, May, 1990, NASA CP 3068

Goddard Space Flight Center, Network Control Center (NCC) User Planning System (UPS) Detailed Design Specification, by Computer Sciences Corp., 1990

**Session 3. Resource Allocation Tools, Technology, and Algorithms**

Johnston, M., SPIKE: AI Scheduling for NASA's Hubble Space Telescope, Proceedings of the Sixth Conference on Artificial Intelligence, March 5-9, 1990, IEEE Computer Society Press, pp. 184-190

Kurtzman, C., Intelligent Perturbation Algorithm for Space Scheduling Optimization, Dec. 1990 (paper included in Appendix D)

Goddard Space Flight Center, A Study of Optimization Techniques for Activity Scheduling, by Computer Sciences Corp., Oct. 1989, DSTL-89-D11

Logan, J. and M. Pulvermacher, Range Scheduling Aid User's Guide, Jan. 1990, WP-6965, MITRE Corp. Bedford, MA

Goddard Space Flight Center, Request-Oriented Scheduling Engine (ROSE) Concepts and Capabilities, by G. Tong, July 1990, DSTL-89-020

Britt, D., A. Geoffroy and J. Gohring, Managing Temporal Relations, 1990 Goddard Conference on Space Applications of Artificial Intelligence, May, 1990, NASA CP 3068

McDonnell Douglas Space Systems Co., COMPASS 1.4, 1989, COMPASS Information Planning and Scheduling Group, Houston, TX

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16. Abstract

This report describes the results of the Space Network Control (SNC) Conference on Resource Allocation Concepts and Approaches, which was held at the Goddard Space Flight Center on December 12-13, 1990. In the late 1990s, when the Advanced Tracking and Data Relay Satellite System is operational, Space Network communicatyion services will be supported and controlled by the SNC. The goals of the conference were to survey existing resource allocation concepts and approaches, to identify solutions applicable to the Space Network, and to identify fruitful avenues of investigation in support of the SNC development. About 75 people took part in the conference, both as speakers and as participants in working-group discussions, to elicit recommendations for the future SNC. The conference was divided into three sessions; 1) Concepts for Space Network Resource Allocation, 2) SNC and User Payload Operations Control Center (POCC) Human-Computer Interface Concepts, and 3) Resource Allocation Tools, Technology, and Algorithms. Key recommendations addressed approaches to achieving higher levels of automation in the scheduling process. Prototyping was mentioned as an effective mechanism for verifying operations concepts and evaluating specific technology risks.

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