N92-11055

837

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

Clifford R. Kurtzman, Ph.D.
Manager, Intelligent Systems
Space Industries, Inc.

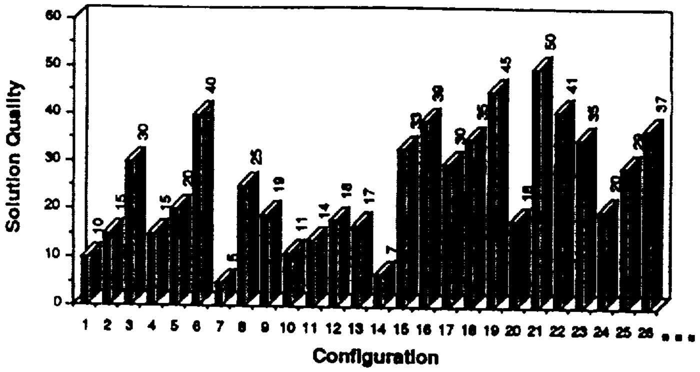
711 W. Bay Area Boulevard, Suite 320
Webster, Texas 77598-4001
(713) 338-2676 FAX: (713) 338-2697
NASAmail: CKURTZMAN
Email: CKURTZMAN@mcimail.com

Why Optimize?

Optimization of planning, scheduling, and manifesting:

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

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

---

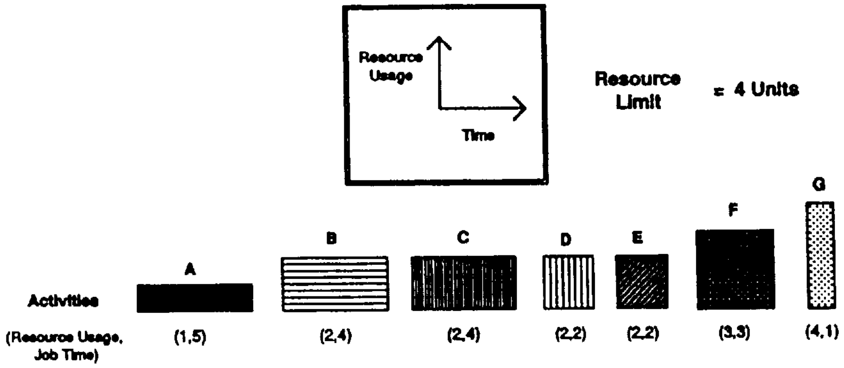
Heuristics Algorithms Are Used For Optimization

- 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

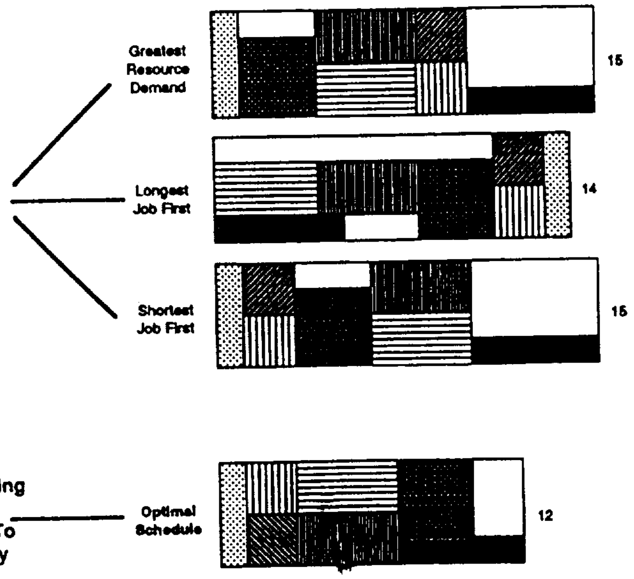
- Polynomial heuristics are used instead of exponential exact techniques to make optimization feasible

Use of Heuristic Methods on a Sample Scheduling Problem



Q-5

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

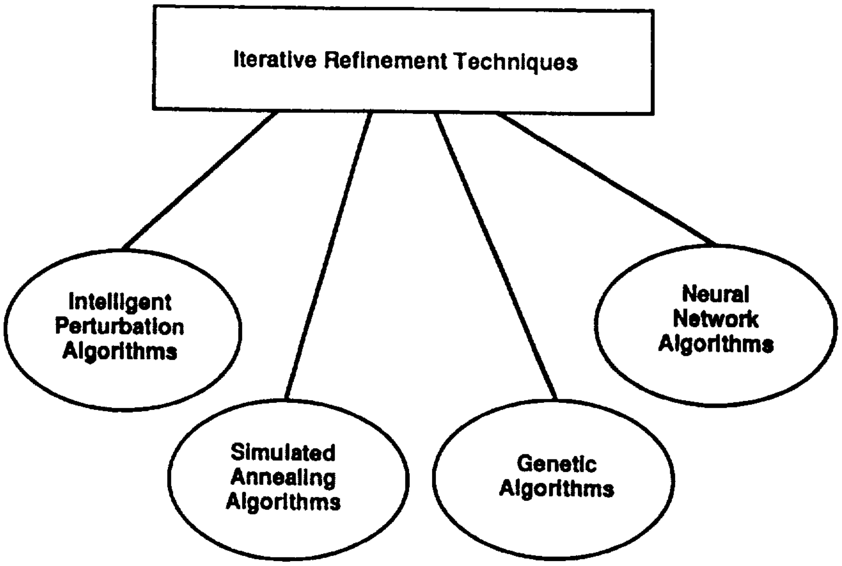


Scheduling Results Using Standard Heuristic Approaches

Space Industries' Scheduling Tools Use Intelligent Perturbation Heuristics To Drive Towards Optimality

Q-6

Intelligent Perturbation Algorithms are Iterative Refinement Techniques


Iterative Refinement Techniques

Intelligent Perturbation Algorithms

Simulated Annealing Algorithms

Genetic Algorithms

Neural Network Algorithms

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

---

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

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

Perturbation Operator Attributes (Dispatching Example)

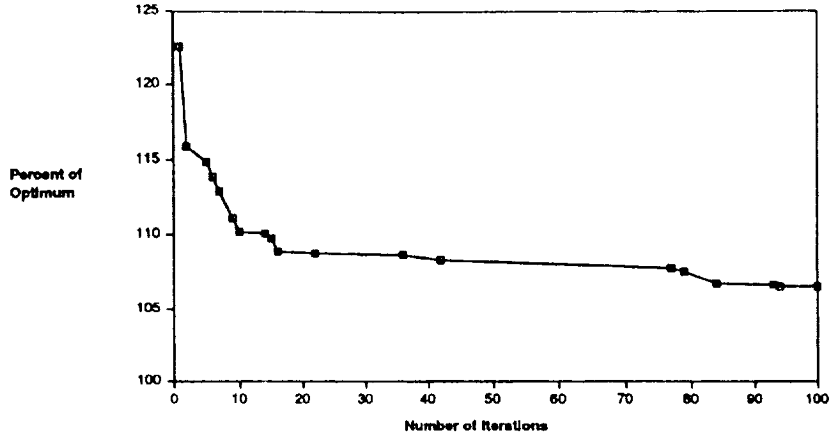
- Increases rankings of activities not satisfactorily scheduled on the previous iteration

- 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**

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

Major Advances in Scheduling Capabilities

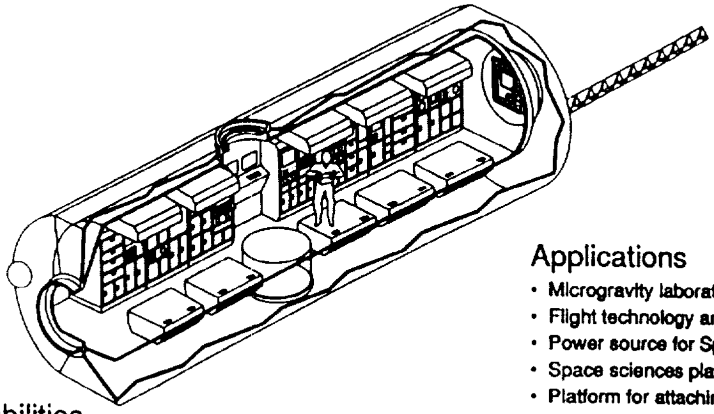
	1980s	1990s
Scheduling Optimization	Iterative Search Techniques	Parallel Processing
Scheduling Software Development	Mouse-Window Style Interactive User-Friendly Interfaces	Object-Oriented Programming Environments

---

The Prototype ISF Experiment Scheduler

SPACE
INDUSTRIES
INTERNATIONAL
INC.

Industrial Space Facility (ISF)



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

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

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

SPACE
INDUSTRIES
INTERNATIONAL
INC.

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.

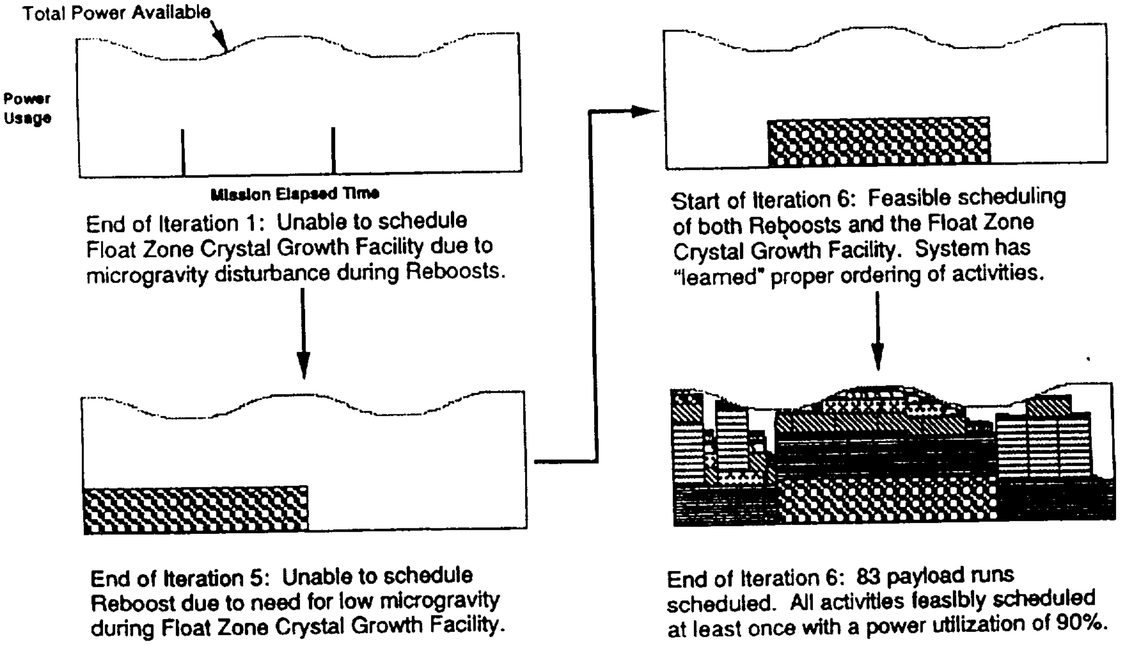
Objectives

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.

The Intelligent Perturbation Algorithm



End of Iteration 1: Unable to schedule Float Zone Crystal Growth Facility due to microgravity disturbance during Reboosts.

End of Iteration 5: Unable to schedule Reboost due to need for low microgravity during Float Zone Crystal Growth Facility.

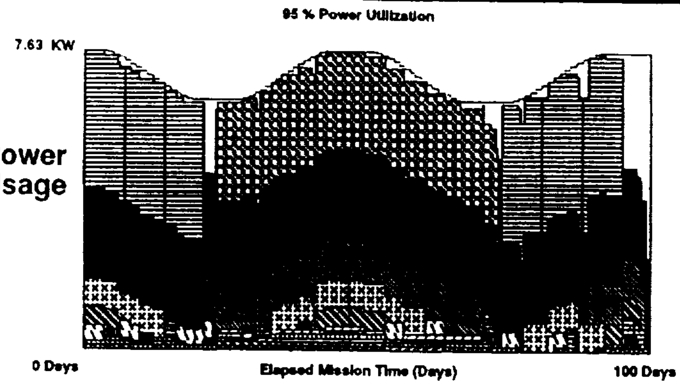
Start of Iteration 6: Feasible scheduling of both Reboosts and the Float Zone Crystal Growth Facility. System has "learned" proper ordering of activities.

End of Iteration 6: 83 payload runs scheduled. All activities feasibly scheduled at least once with a power utilization of 90%.

SPACE
INDUSTRIES
INTERNATIONAL
INC.

SPACECRAFT Planning and Scheduling Systems and Services

Optimized Schedule (Max Revenue)

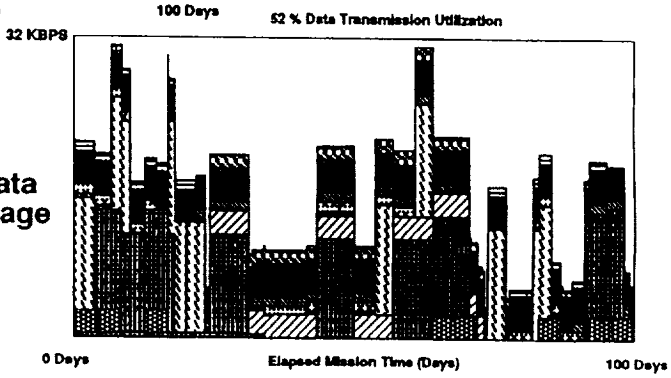


Power Usage

19 Selected Experiments from MMPF Data Base

▧ 4 AADSF
■ 8 CVT-I
▨ 12 DMOS
▩ 17 EDEP
▤ 19 EML
▦ 21 FZCGF
■ 27 GFGAS
▦ 34 IDGE
▥ 41 MIS
▧ 47 MLRS
▩ 49 MEPF
▧ 50 NLOM
▨ 51 NLOOC
▨ 52 NLOTF
▦ 53 NFF
▦ 55 ORSEP
▦ 58 PVTOS
▤ 59 PMO
▤ 63 SURF
■ 71 REBOOST
■ 72 REBOOST

ID #	Experiment Name	Runs Scheduled	Max Runs Requested
4	Advanced Automated Directional Solid. Fur.	4	8
8	Chemical Vapor Transport - I	6	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	6
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	8
50	Non-Linear Optical Monomers	1	3
51	Non-Linear Optical Organic Crystals	1	2
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
63	Space Ultra-Vacuum Research Facility	6	8
71	Reboost	1	1
72	Reboost	1	1
Total		84	110



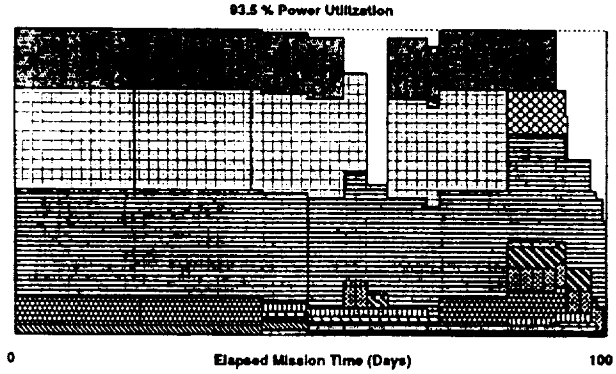
Data Usage

SPACE
INDUSTRIES
INTERNATIONAL
INC.

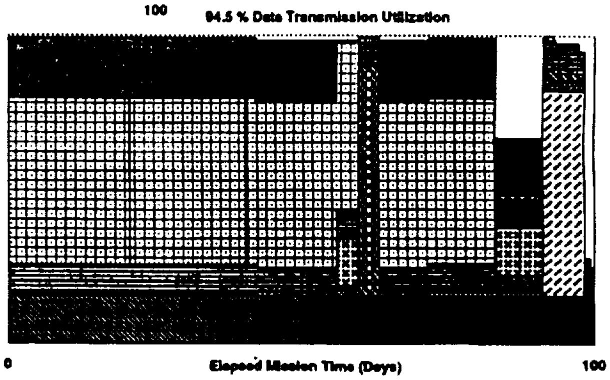
SPACECRAFT Planning and Scheduling Systems and Services

Multi-Variable Optimization

ISF Payload Scheduling



Power Usage



Data Usage

18 Selected Experiments from MMPF Data Base

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.

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

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.

Example Task: Communications Check

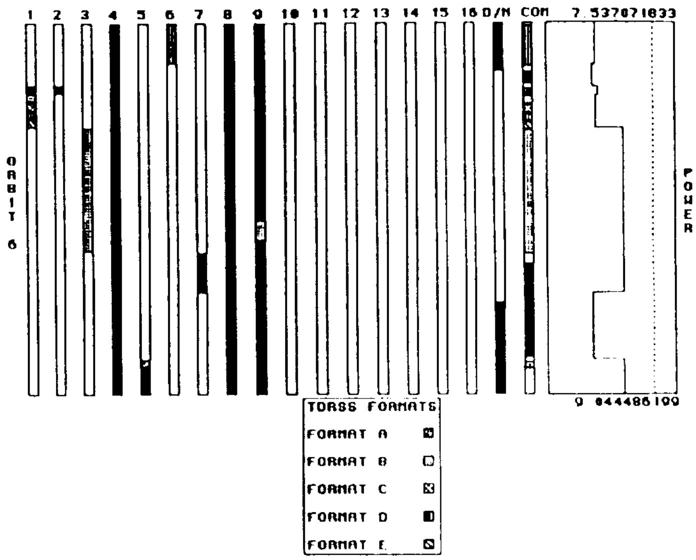
Duration: 10 minutes, consisting of 5 consecutive 2 minute segments

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).

ISF - TDRSS Command Scheduling Demonstration - Orbit 6



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