



National Aeronautics and Space  
Administration  
**Jet Propulsion Laboratory**  
California Institute of Technology

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# Market-Based Systems: Bidding your way to the Launch Pad

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# Agenda

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- Introduction
- Cassini Science Instrument Development
- Space Shuttle Manifests
- LightSAR Mission Planning
- Market-Based Systems Applied to NASA  
Resource Allocation Problems
- Conclusions

# Introduction

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- Problem - How to allocate scarce resources among many users?
  - ◆ Users do not have an incentive to reveal accurate information.
- Current Approach:
  - ◆ Benevolent Dictator - Impartial individual making decisions for user community.
  - ◆ Committee - “Consensus” reached by user representatives.
- New Approach:
  - ◆ Market-based systems - Decentralized incentive-based decision-making at the user level.

# Introduction (cont.)

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- Market-based systems use “rights” and “trades” to resolve conflicts.
  - ◆ Users:
    - Own clearly defined resources.
    - Decide the importance of their resources.
    - Enhance their own position by exchanging resources among themselves.

# Introduction (cont.)

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- Market-based systems require that an “economy” be created.
- To create an economy, the following must be defined:
  - ◆ Resources to be allocated.
  - ◆ Resource ownership rights.
  - ◆ Rules for making and keeping track of trades.

# Introduction (cont.)

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- Market-based systems have two major phases:
  - ◆ Initial Allocation (Primary Market) - Users use “currency” to establish property rights over resources.
  - ◆ Aftermarket (Secondary Market) - Users can voluntarily trade their resources with others to enhance their value.

# Introduction (cont.)

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- Examples of Market-based systems used in private industry:
  - ◆ Best Buy
  - ◆ Corning
  - ◆ Federal Communications Commission
  - ◆ General Electric
  - ◆ Google
  - ◆ Hewlett-Packard
  - ◆ Koch Industries
  - ◆ Microsoft
  - ◆ RECLAIM Program in Southern California
  - ◆ Sandia National Laboratories
  - ◆ Sears Logistic Services
  - ◆ University of Chicago Business School
  - ◆ University of Michigan
  - ◆ University of San Diego

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# The Cassini Instrument Development

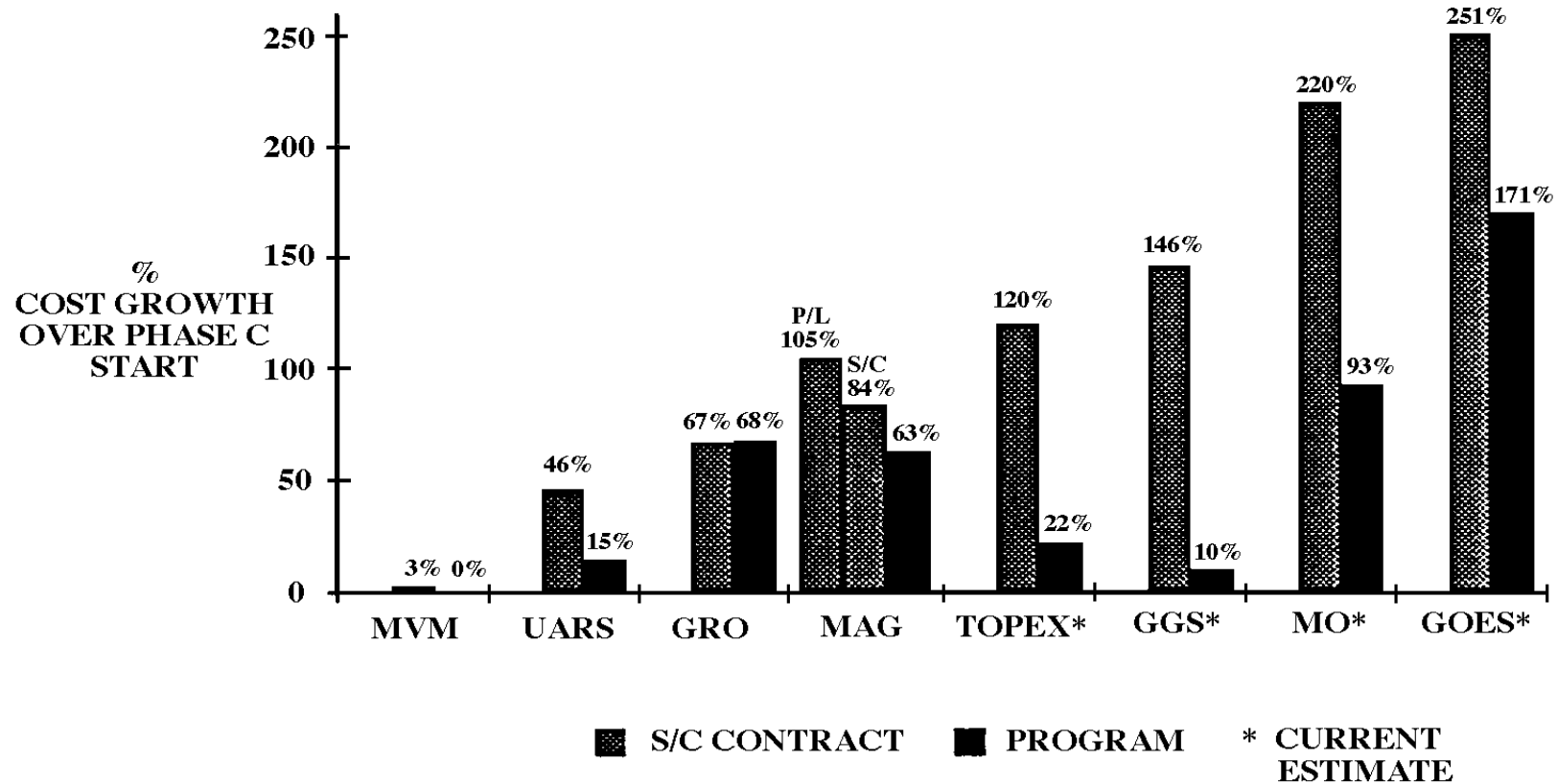
# Cassini Instrument Development

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- Typical instrument development for planetary missions require:
  - ◆ Project's to submit a Request for Proposals.
  - ◆ Project's acceptance of Principal Investigators' proposals.
- Data from previous missions show that instrument mass and cost growths are:
  - ◆ Almost always positive.
  - ◆ Can be very large.

# Cassini Instrument Dev. (cont.)

Percent Growth for Past Space Missions



# Cassini Instrument Dev. (cont.)

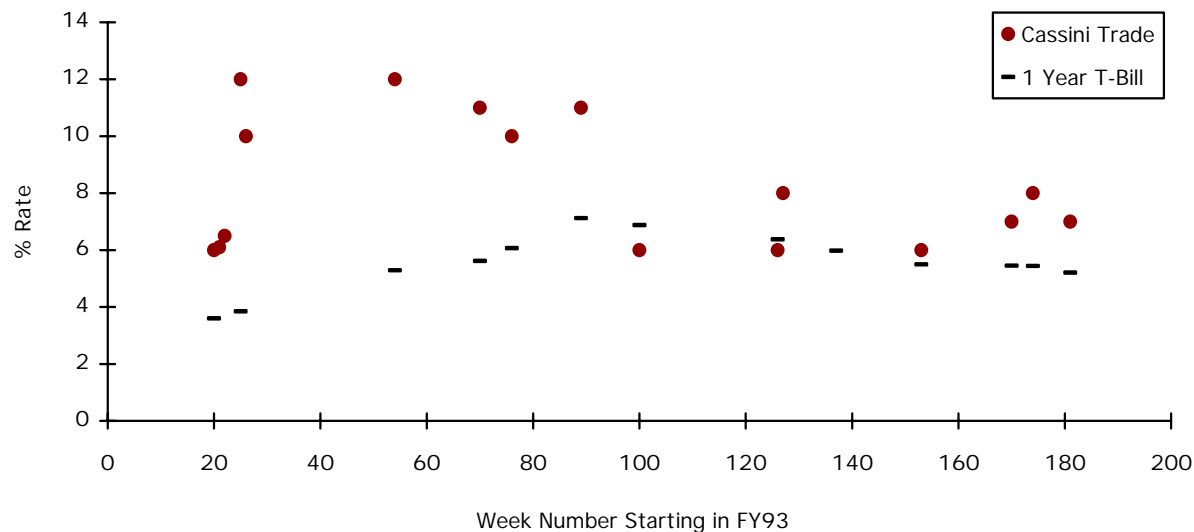
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- In 1992 a Market-based Aftermarket, known as the Cassini Resource Exchange (CRE), was developed.
  - ◆ Based on experiments conducted at Caltech with student subjects and science personnel.
- Instrument mass, power, data rate, and funding were allowed to be traded.
  - ◆ The CRE opened in 1993 and closed in 1995.
    - 29 successful trades were made, all but two involved money and mass.

# Cassini Instrument Dev. (cont.)

- Example of a money-market trade:
  - ◆ \$200k this FY in return for \$212k next FY = 6%.
- 16 contracts, worth \$4M, were traded at an average rate of 8.5%.

Fig 2. Money Market Activity

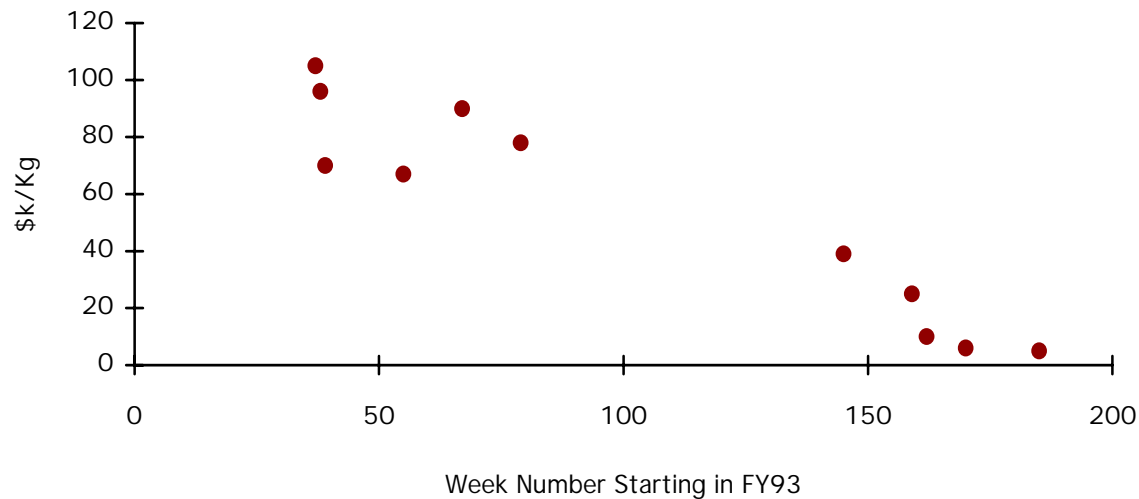


# Cassini Instrument Dev. (cont.)

- Mass-market trades:

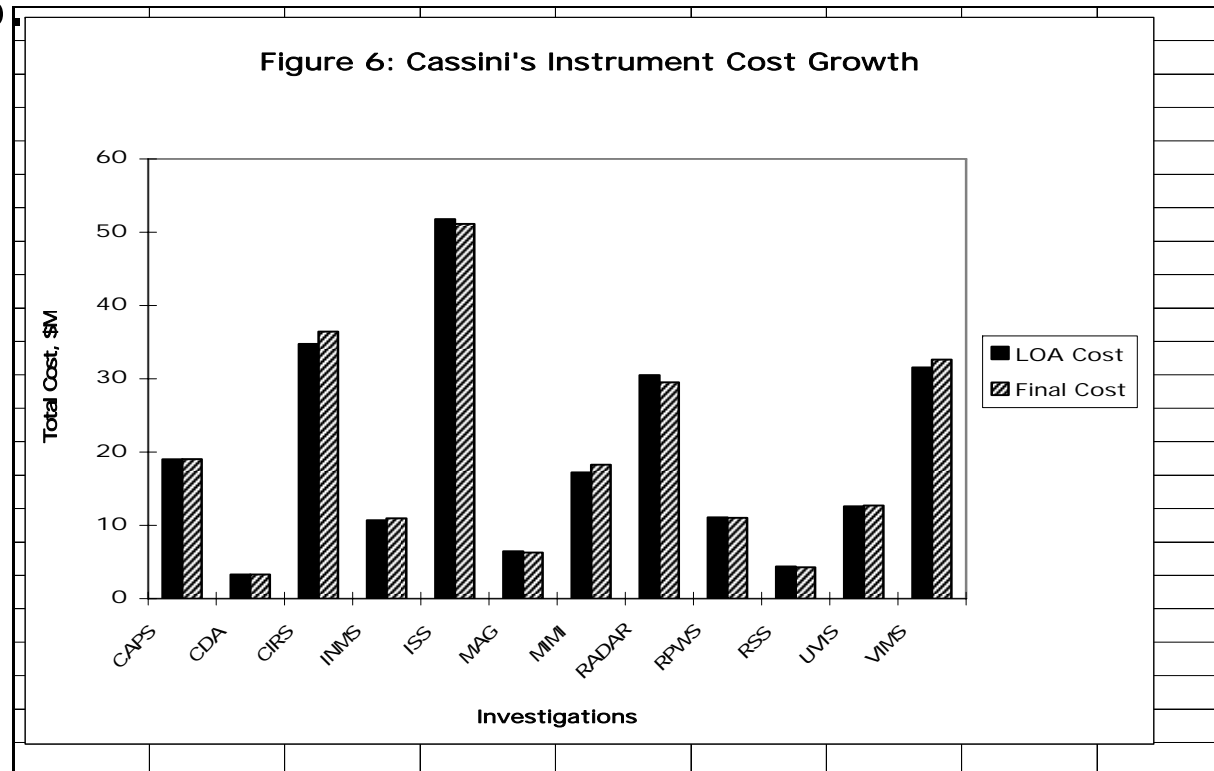
- ◆ Mass started at \$105k/kg and fell to \$5k/kg.
- ◆ 11 contracts for a total of 12 kg were traded.

Figure 5: Mass Market Activity



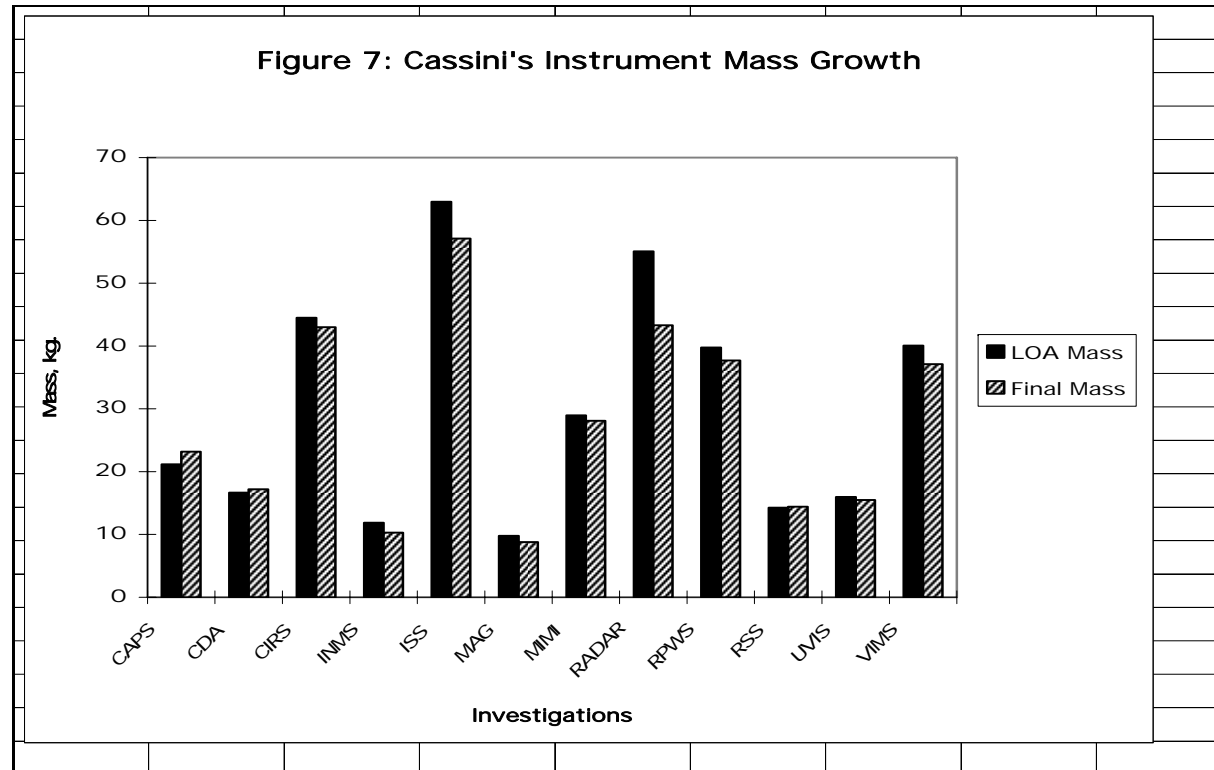
# Cassini Instrument Dev. (cont.)

- Cost for the entire science payload grew by <math><1\%</math>



# Cassini Instrument Dev. (cont.)

- Mass for the entire science payload decreased by 7%.



# Cassini Instrument Dev. (cont.)

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- In 1998 a Market-based system was developed for Cassini science planning.
  - ◆ Web-based application.
    - Password protected.
  - ◆ Used to allocate observation time, CDS words and data volume.
  - ◆ Compatible with JPL's Mission Sequence Software System (e.g., APGEN)

# Cassini Instrument Dev. (cont.)

- Cassini science planning bid sheet.

CIRS Observation Requests

ReConnect      Priority Points Available: 1000

Close      Priority Points in Use: 0

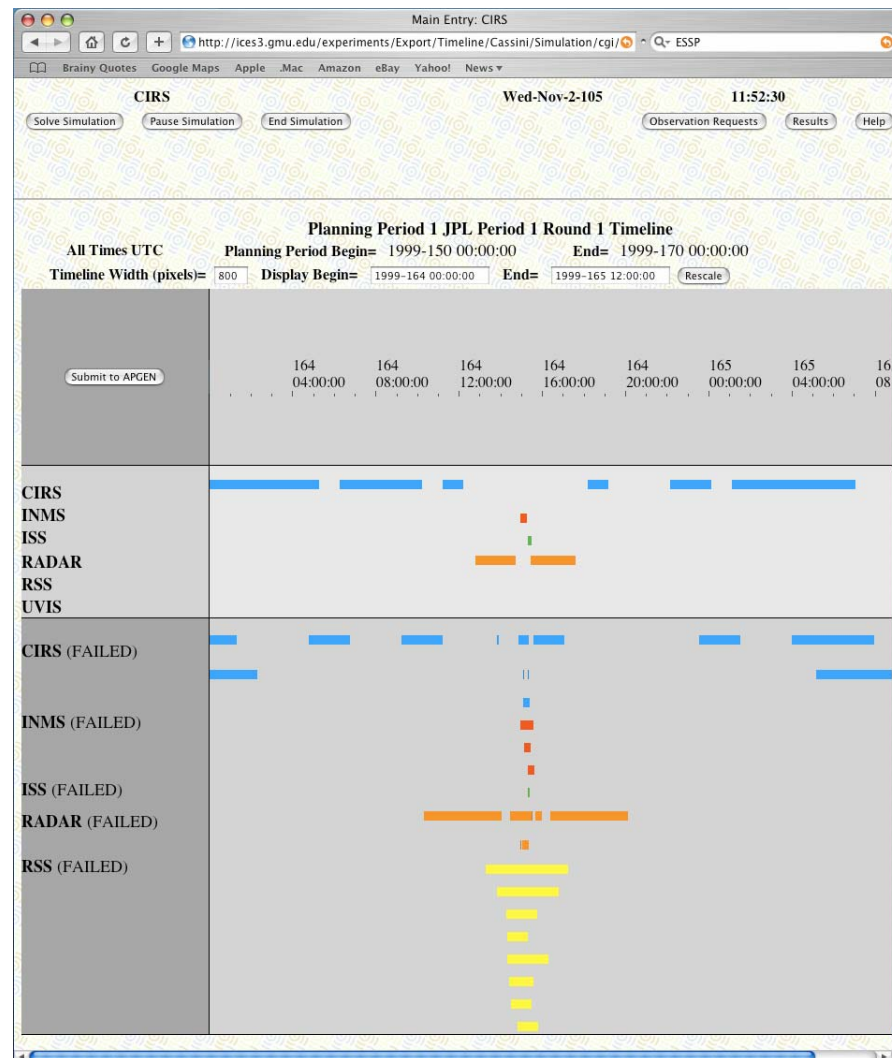
Done

Obs. Status	Obs. Name	Start Time	End Time	Duration (min)	DataVolume (Mbits)	CDS Words (words)	Priority
New	MIRmap111	163 / 15 : 19 : 00	163 / 19 : 19 : 00	4 : 0 : 0	4	22	Priority 6 0
New	MIRmap112	163 / 17 : 19 : 00	163 / 21 : 19 : 00	4 : 0 : 0	4	22	Priority 6 0
New	MIRmap114	163 / 18 : 19 : 00	163 / 21 : 19 : 00	3 : 0 : 0	4	22	Priority 6 0
New	FIRint111	163 / 21 : 19 : 00	164 / 01 : 19 : 00	4 : 40 : 0	11	6	Priority 6 0
New	FIRint112	163 / 22 : 19 : 00	164 / 02 : 19 : 00	4 : 40 : 0	11	6	Priority 6 0
New	FIRint113	163 / 23 : 19 : 00	164 / 03 : 19 : 00	4 : 40 : 0	11	6	Priority 6 0
New	MIRlmbmap111	164 / 03 : 19 : 00	164 / 05 : 19 : 00	2 : 0 : 0	7	19	Priority 6 0
New	MIRlmbmap112	164 / 04 : 49 : 00	164 / 06 : 49 : 00	2 : 0 : 0	7	19	Priority 6 0
New	MIRlmbmap113	164 / 06 : 19 : 00	164 / 08 : 19 : 00	2 : 0 : 0	7	19	Priority 6 0
New	FIRmap111	164 / 08 : 19 : 00	164 / 10 : 19 : 00	2 : 0 : 0	9	5	Priority 6 0
New	FIRmap112	164 / 09 : 19 : 00	164 / 11 : 19 : 00	2 : 0 : 0	9	5	Priority 6 0
New	FIRlmbint111	164 / 11 : 19 : 00	164 / 12 : 19 : 00	1 : 0 : 0	13	11	Priority 6 0

# Cassini Instrument Dev. (cont.)

- Cassini Science Planning Tool.

- ◆ Timeline is always conflict-free.
- ◆ Provides user feedback to get observation requests accepted.
- ◆ This system was never tested.



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# Space Shuttle Manifests of Secondary Payloads

# Space Shuttle Manifests

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- Typical approach for manifesting Space Shuttles Secondary Payloads require:
  - ◆ NASA User Codes to submit requests for payload lockers.
  - ◆ Manifestors at NASA Headquarters allocate lockers in such a way to:
    - Utilize Space Shuttle resources to capacity.
    - Be “fair” to the User Codes.

# Space Shuttle Manifests (cont.)

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- Multiple meetings required to:
  - ◆ Present current manifest.
  - ◆ Explain why some payloads were included while others were not.
  - ◆ Obtain payload trade-off information.
- Manifestors required to re-manifest secondary payloads after each meeting.

# Space Shuttle Manifests (cont.)

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- In the summer of 1996 a Market-based Initial Allocation experiment was developed for NASA's Office of Space Utilization.
  - ◆ Market-based approach was compared to a simple ranking approach.
  - ◆ Secondary payload lockers, energy, and crew hour requirements were allowed to be requested.

# Space Shuttle Manifests (cont.)

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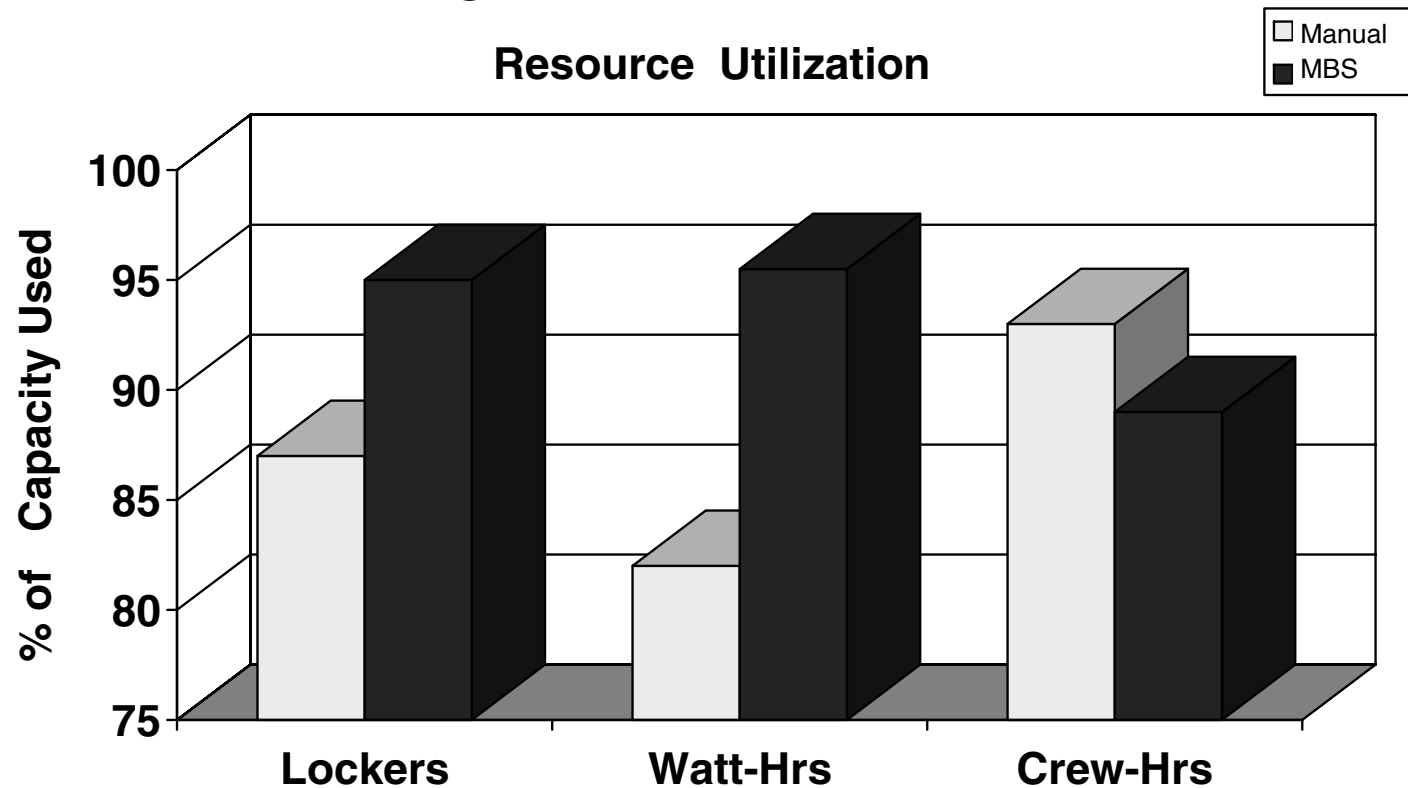
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- Office of Space Utilization personnel performed the simple ranking manifest.
  - ◆ Results were compared to market-based results.
- Real payload data was used.
  - ◆ A “science return” value and payload rank were included to measure the caliber of the manifest.

USER	P/L	LOCKERS	WATT-HRS	CREW-HRS	SCIENCE RETURN	RANK
Code U	MGBX-01	6	237	56	100	1
Code U	CGBA-04	4	136	5.166	70	2
Code U	CPCG-07	1	128	5.833	55	2
Code U	CPCG-08	1	128	2	45	3
Code U	PCG-TES-02	3	115	0	40	3

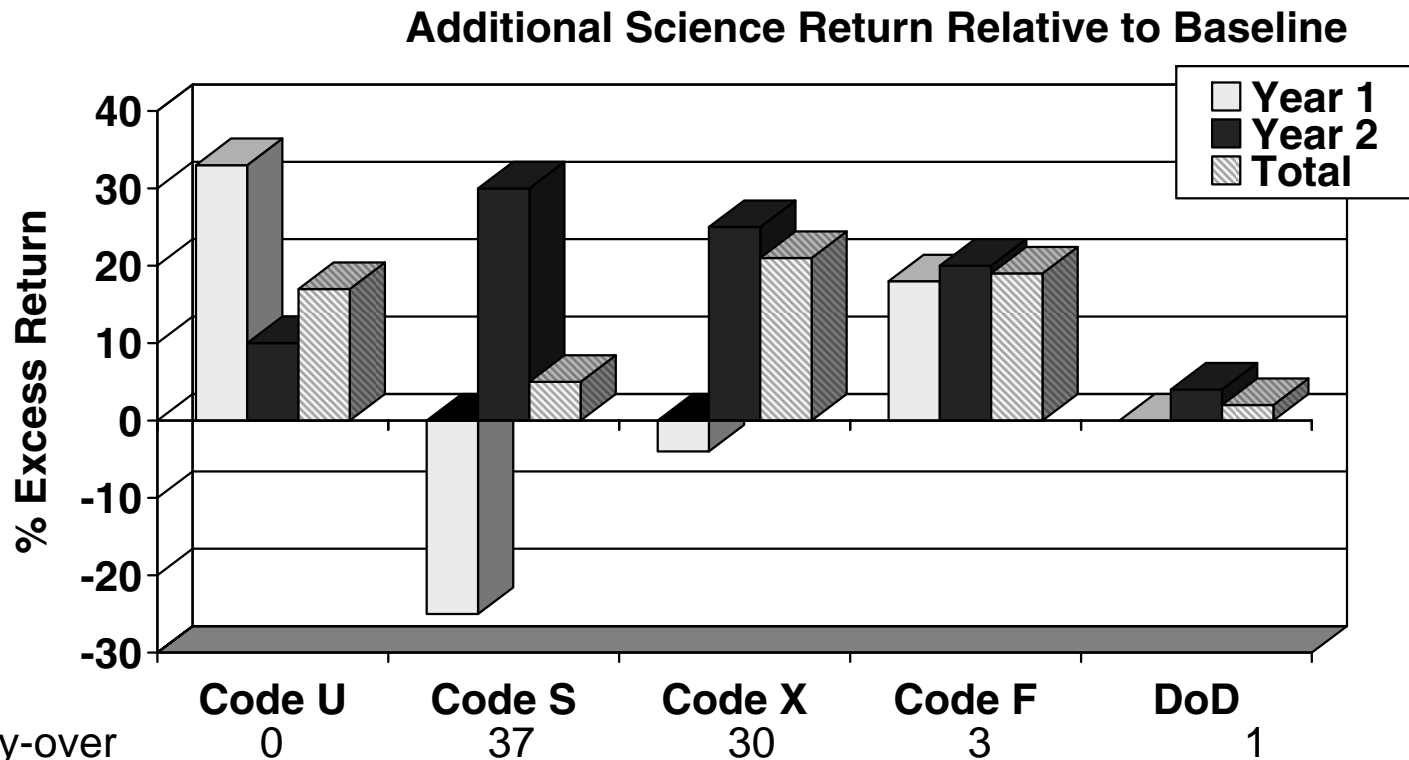
# Space Shuttle Manifests (cont.)

- Comparison of resource utilization between a simple ranking vs a market-based approach.



# Space Shuttle Manifests (cont.)

- Comparison of science value for a simple ranking vs a market-based approach.



Point carry-over  
Year 1 to Year 2

# Space Shuttle Manifests (cont.)

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- Market-based systems have already handled the following type of problem:
  - ◆ Manifest space shuttles middeck lockers efficiently
  - ◆ 6 Users
  - ◆ 47 variables/payload
  - ◆ 1,500,000 payload requests
  - ◆ Solutions found in an average of 2.5 minutes

# Space Shuttle Manifests (cont.)

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- Implementation of a market-based system is “on-hold” until:
  - ◆ The full impact of the International Space Station’s requirements on middeck lockers can be determined.
  - ◆ “Nominal” Space Shuttle missions resume.

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# LightSAR Mission Planning

# LightSAR Mission Planning

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- LightSAR was a NASA initiative to develop a low-cost Earth-imaging RADAR satellite.
- Typical approach for mission planning:
  - ◆ Submit data take requests.
  - ◆ Create integrated timeline.
  - ◆ Multiple meetings to resolve conflicts.
  - ◆ Re-Integrate timeline.

# LightSAR Mission Planning (cont.)

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- In the winter of 1997 a Market-based Initial Allocation experiment was developed for LightSAR mission planning.
  - ◆ Users were assigned a specific data acquisition type (e.g. Hi-Res Strip, Spotlight, Interferometry, Dual Polarimetry, etc.).

# LightSAR Mission Planning (cont.)

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- A data request, rank and “science return” value were included with each request to measure the caliber of the manifest.

Dual Polarimetry Requests

Location	Orbit Number	Data Take Number	Rank	Value
Vietnam	1	1	1	60
Kuala Lumpur	1	3	2	45
Indonesia	1	4	2	35
Cambodia	2	3	3	10

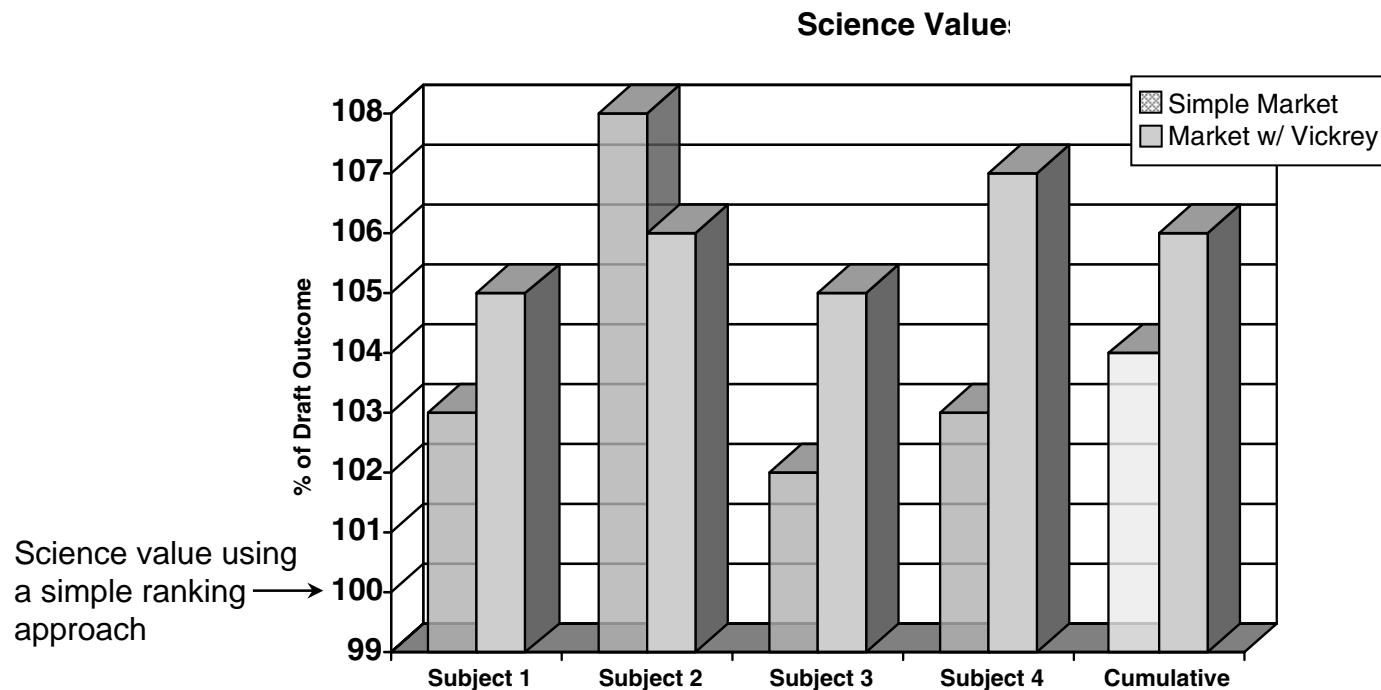
# LightSAR Mission Planning (cont.)

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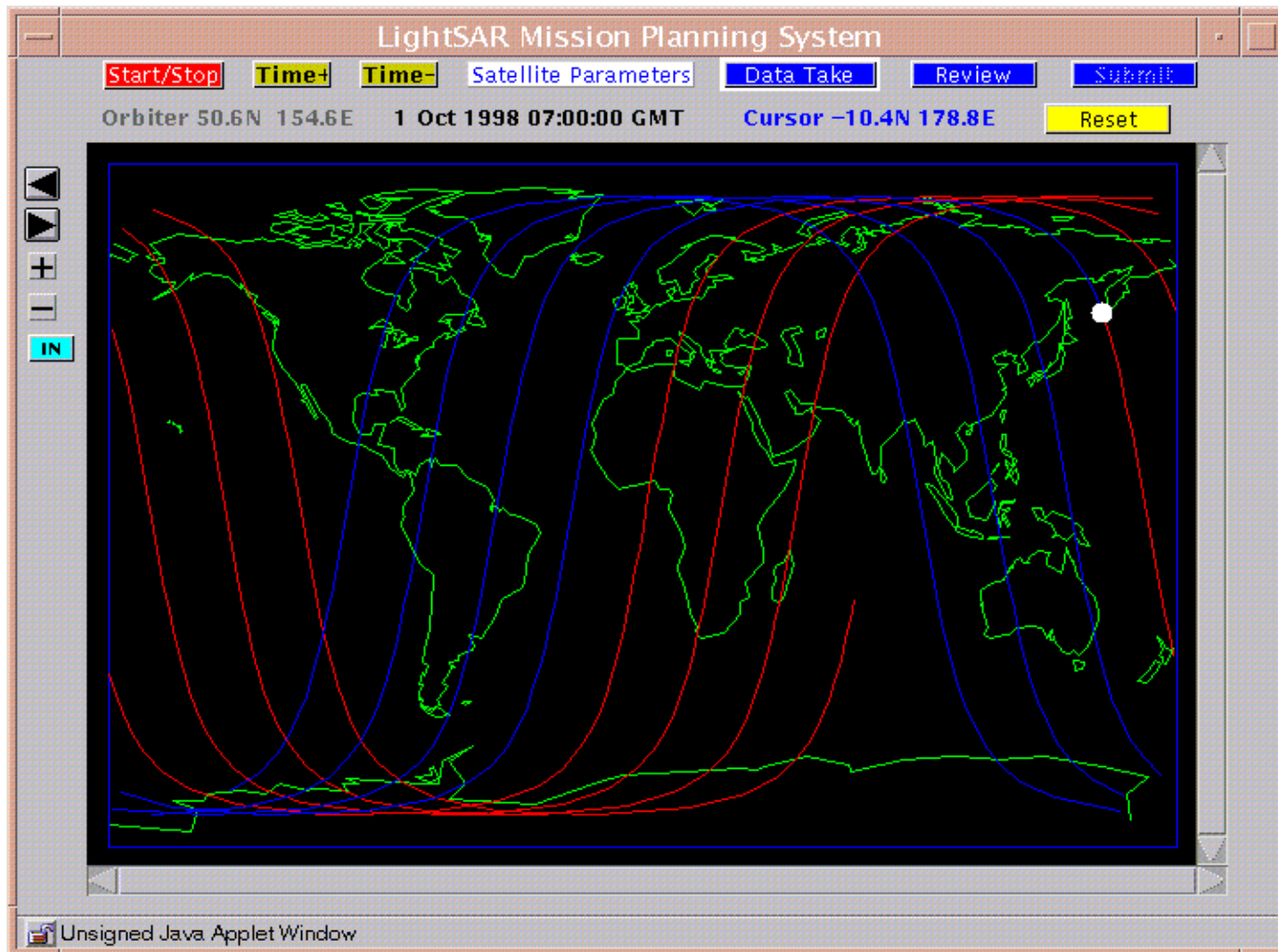
- In a market-based approach, Users bid for a “higher priority” request.
  - ◆ The higher the priority, the greater the probability of getting into the timeline.
  - ◆ A Vickrey Auction was used to provide “incentives” for the Users to be forthright about their bids.
    - In a Vickrey Auction “winners” pay the runner-up price.

# LightSAR Mission Planning (cont.)

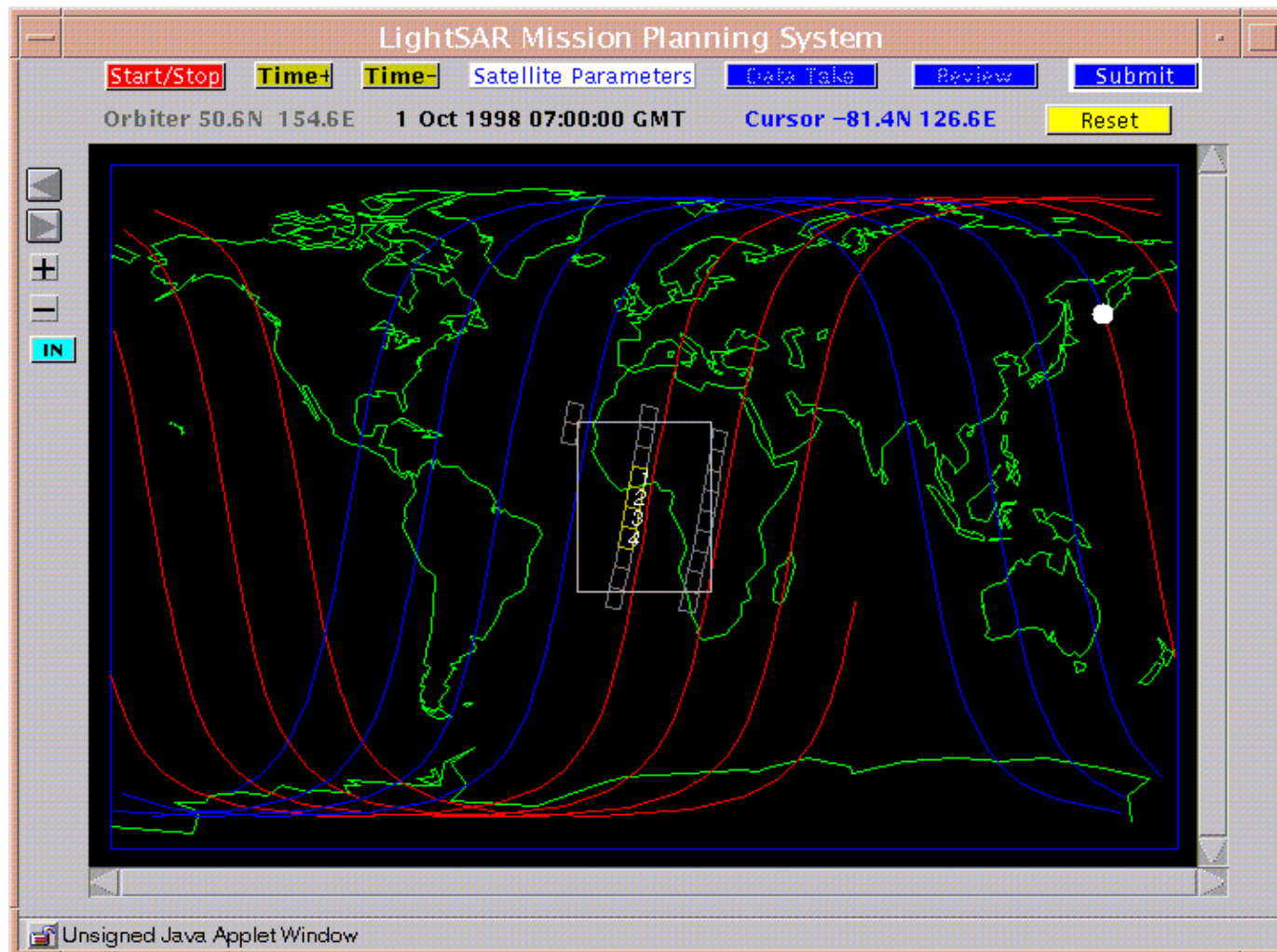
- Comparison of the science value between a simple ranking, a simple market, and a market using a Vickrey Auction.



# LightSAR Mission Planning System (cont.)



# LightSAR Mission Planning System



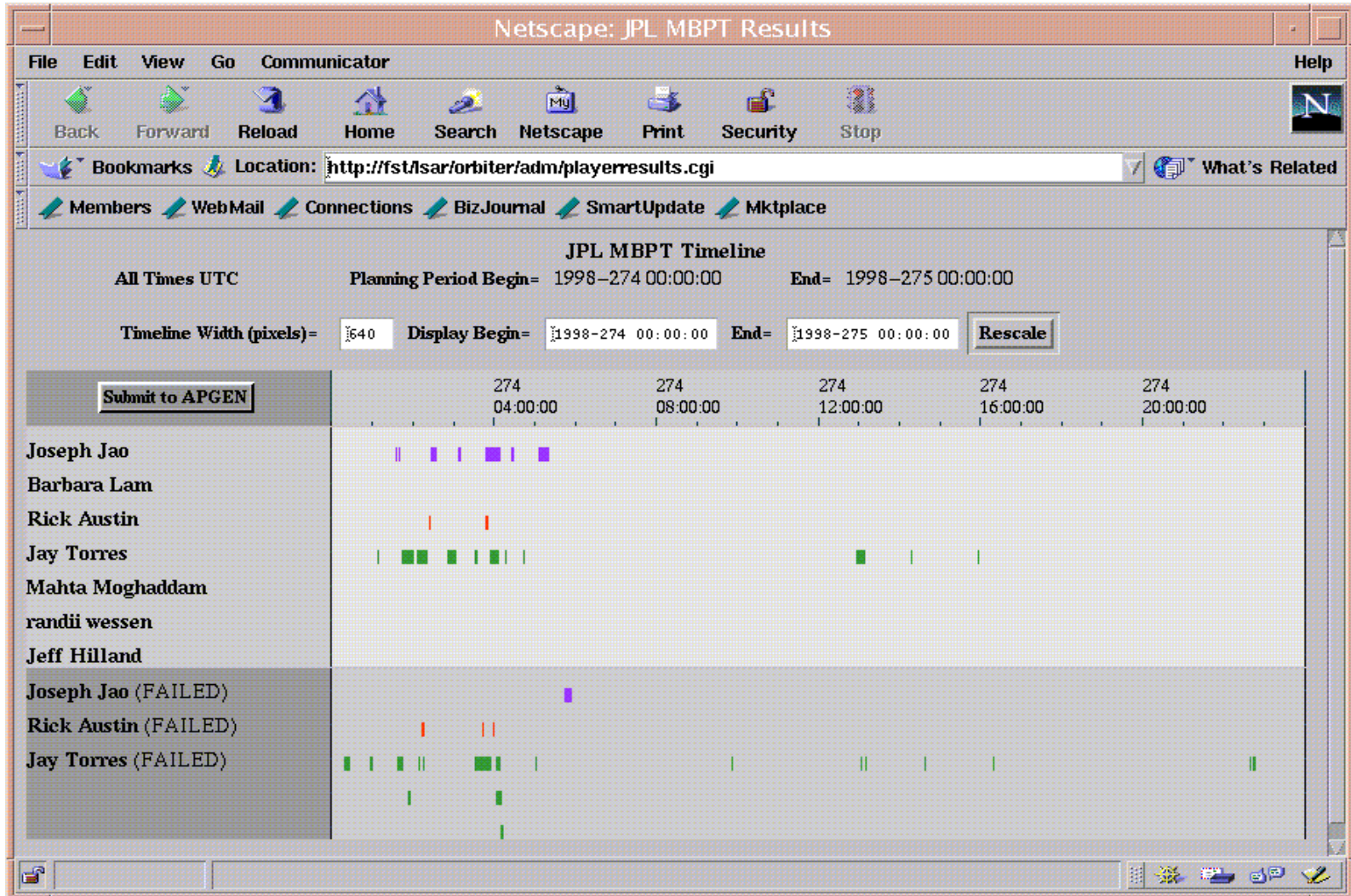
# LightSAR Mission Planning (cont.)

<i>Frame</i>	<i>Begin Time</i>	<i>End Time</i>	<i>Priority</i>	<i>Group</i>
1	273 22:52:30	273 22:54:00	6 <input type="checkbox"/>	None <input type="checkbox"/> None <input type="checkbox"/> None <input type="checkbox"/>
2	273 22:53:59	273 22:55:29	6 <input type="checkbox"/>	None <input type="checkbox"/> None <input type="checkbox"/> None <input type="checkbox"/>
3	273 22:55:30	273 22:57:00	6 <input type="checkbox"/>	None <input type="checkbox"/> None <input type="checkbox"/> None <input type="checkbox"/>
4	273 22:57:00	273 22:58:30	6 <input type="checkbox"/>	None <input type="checkbox"/> None <input type="checkbox"/> None <input type="checkbox"/>

**Budget: 120**

Unsigned Java Applet Window

# LightSAR Mission Planning (cont.)



# LightSAR Mission Planning (cont.)

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- Experiments revealed only minor operational problems.
  - ◆ Lack of experience seemed to be the largest.
- LightSAR was canceled.
- A new RADAR mission called INSAR has begun concept studies.
  - ◆ The work on LightSAR can be used for INSAR and will be pursued.

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# Market-Based Systems Applied to NASA Resource Allocation Problems

# NASA Market-Based Systems

Task	Start	End	Status
Cassini Instrument Development	1993 Sept	1995 April	Successfully controlled mass and cost growth.
Space Shuttle Manifests	1996 Dec	1997 Sept	Never made it past experiments.
LightSAR Mission Planning	1997 Dec	1998 Sept	Mission canceled.
Cassini Science Planning	1998 April	1999 Mar	Never performed experiments with users.
Mars'01 Science Planning	1999 April	1999 Dec	Mission canceled.
International Space Station Manifests	2000 Sept	On Hold	Never performed experiments with users.
Alternate Workforce Allocations	2000 Jun	2002 Jan	Never performed experiments with users.
Deep Space Network Antenna Allocation	2005 Jan	2005 April	Never performed experiments with users.

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# Conclusions

# Conclusions

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- Cassini, Space Shuttle, and LightSAR benefited (or could benefit) from the use of a market-based process.
- Resource allocation problems can be solved with the use of market-based systems.
  - ◆ Data shows that market-based systems can produce results:
    - As good (or better) than the current processes.
    - Are reached quicker and with a smaller workforce.

# Conclusions

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- The strengths of market-based systems are that they:
  - ◆ Move the decision making process back to the individuals that have the information, namely the users.
  - ◆ Are electronically based on the Web and thus can be globally distributed.
  - ◆ Remove the need for multiple meetings and appeals.

# Conclusions

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- One perceived short coming of market-based systems is their initial allocation.
  - ◆ However, all processes have initial allocation problems.
  - ◆ Better to solve one large problem early then multiple smaller problems late in a given process.
- Most individuals outside of experimental economics do not appreciate the power of market-based systems.

# Conclusions

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- In order to successfully implement a market-based system it is recommended that it be used in parallel with the current approach to “gently” help users understand its application.
- There will be resistance to change to a new system, even a more efficient one.
  - ◆ Winners are not sure that they’ll do as well as compared to the current process.
  - ◆ Losers are not sure that they’ll do better as compared to the current process.
  - ◆ Integrators lose their jobs.
  - ◆ Managers will express a loss of control.

# Conclusions

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- Top 5 “bad” reasons for not using a market-based system:
  5. *“Market-based systems can solve resource allocation problems, but my problem is different.”*
  4. *“We don’t have a resource allocation problem, we just just have a scheduling problem.”*
  3. *“There’s no way to come up with an initial allocation of resources.”*
  2. *“Too many people will lose their jobs.”*
  1. *“We don’t need a market-based system to solve our problems. We’ll just solve it in a collegial manner.”*