# 1 Evaluation of the. Cassini Resource Exchange

RECEIVED
JUL 17 1996
I.J. MILLER

Randii R. Wessen

MS 301-?501 )
California Institute of' Technology
Jet Propulsion Laboratory '"
4800 Oak Grove drive
Pasadena, California 91109

David Porter

California Institute of Technology
Pasadena, California 91125

ABSTRACT

The Cassini Resource 1 Exchange was developed to assist the Cassini Science Instrument Manager with the management of the spacecraft's science payload. This system, unlike previous development approaches, allocated the entire mass, power, data rate, and budget resources for the science instruments to the Principal Investigators. The result removed the Cassini Project from solving instrument development issues. Problems that did occur were resolved by the Principal Investigators themselves through the use of a "resource exchange." A resource exchange allowed Principal Investigators to submit "bids" (i .e., a request for resources) to a database. Any other Principal Investigator with their own resource issue could swap resources with investigators in the database. The resulting trade could mitigate both instrument problems.

KEYWORDS: Spacecraft, Cassini, Instrument, Development

## 1.0 INTRODUCTION

The quality of the data returned by a planetary mission is directly related to the caliber of its instrument package. However, during instrument development a number of unforeseen resource issues may arise that directly impact the quality of those instruments. Unexpected increases in instrument mass, power, data rate or cost may force the Principal Investigator (1'1 ) to reduce the capability of their instrument if additional resources cannot be found. In extreme cases, instruments that exceeded their resource envelope have been removed from the spacecraft. Thus, how a project addresses instrument resource issues during Development directly affects the science return from the mission.

This paper will compare the past approach for the allocation of instrument resources to the approach used by the Cassini Project. In this paper, instrument development growth on Mars Observer (MO) will be compared to those on Cassini. Mars Observer was used since it represents the most recent multi-instrument spacecraft for which data is available.

## 2.0 I'AS'I' lNS'1'R[JMI12WJ'1 )EVELOPMENT APPROACHES

Past instr ument development approaches continue to evolve, building upon lessons learned from previous approaches. In general, the individual responsible for guiding the instruments through 1 )evelopment is the Project's Science Instrument Manager (SIM ). The SIM's role begins with reviewing the instrument proposals. These proposals responded to a Request 1 'or Proposals (RI 'J') sent out by the National Aeronautics and Space. Administration (NASA).

The SIM, along with a small [Cain of experts with backgrounds in mechanical systems and avionics, evaluate the proposals for technical and managerial content. '1 'he troll) determines the degree of' compatibility of each proposed instrument to the planned spacecraft bu s. Their results are reported bad to NASA. Independently, NASA selects a science review bead to evaluate each proposal and rank them according to their ability to meet the science objectives of the mission. Final selection of the instrument payload adeby the NASA Associate Administrator for Space Science.

Once selected, the 1'1s sign a Letter of Agreement (LOA) specifying the resources that will be required to build the.ir instrument. In essence, these letters are contracts with the project, committing it to provide a resource envelope in which an investigator can build an instrument for their spacecraft. In return, the 1'1 commits to building the. proposed instrument for a specific cost and delivery date. Typically the contract is for two instruments; an Engineering Model, used to qualify the instrument in a simulate.d space environment, and a Flight Model, which will be attached to the spacecraft and launched to the target body.

During instrument development, many problems typically occur. These problems arise from the level of risk accepted by the 1'1. In most cases, developmental risk comes from the 1'1's desire to built a slate-of-tlm art instrument needed for a thorough investigation of the intended target. As the problems occur, the PI's Instrument 1 Engineer (IE) reallocates resources to rc.solve the issues. Unfortunately, some of" these challenges require more resources then are available to the IE.

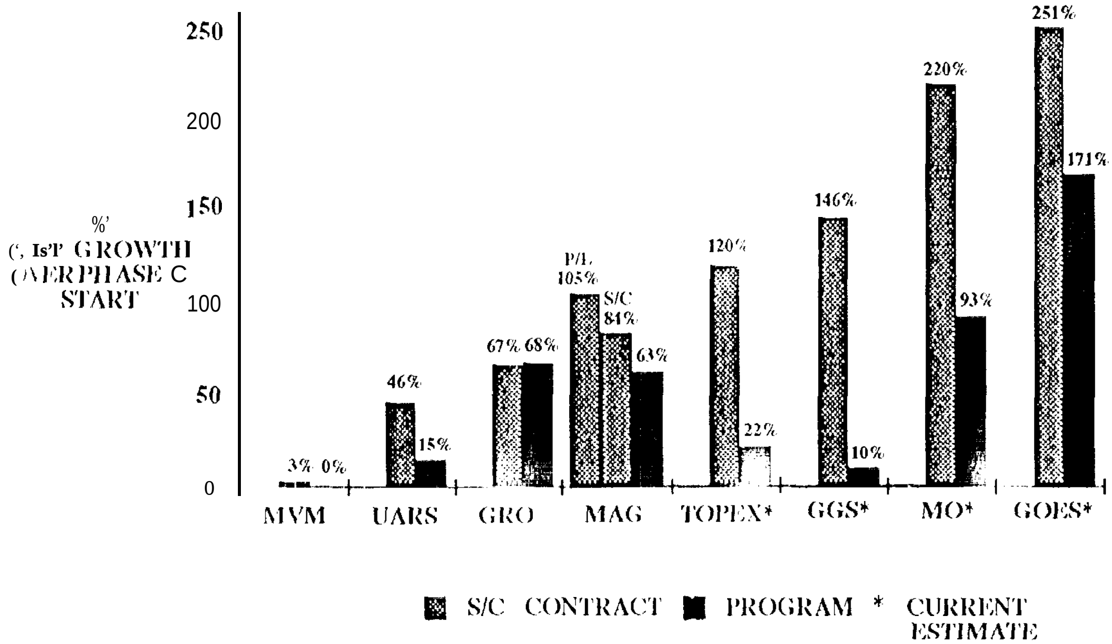
When an insurmountable problem appears, the 1'1 turns to the SIM for additional resources. At this point the SIM has many questions to address. Some of them are:

1, Do 1 have the required resources to solve the problem?
2. 1 )oes the instrument problem result from an increase in instrument scope 01 just a technical issue associate.d with the dc.sired instrument?
3. Will other investigations develop problems that will require the resources used to solve the current instrument problem?
4. If there are future instrument problems, will they be more important to solve than the current instrument problem?

Obviously, many of these questions can not be answered apriori. However, what is known is that instrument teams care mostly about the quality of the.iJ own instrument, the quality of any instrument increases with the increase of resources assigned to it, and that at least one of the selected instruments will require an increase in resources. '1'able 1 Snows the percent cost growth of past spacecraft contracts and their associated progr ares. Note that instrument cost growths are included in the spacecraft contract cost.

As the table clearly shows, cost growth is a common factor in the development of any spacecraft. What is not clear, is hOw to mitigate the cost for additional resources in the fixed-]wim environment for building today's spacecraft.

**Table 1: Percent Cost Growth for Past Space Missions**[1]



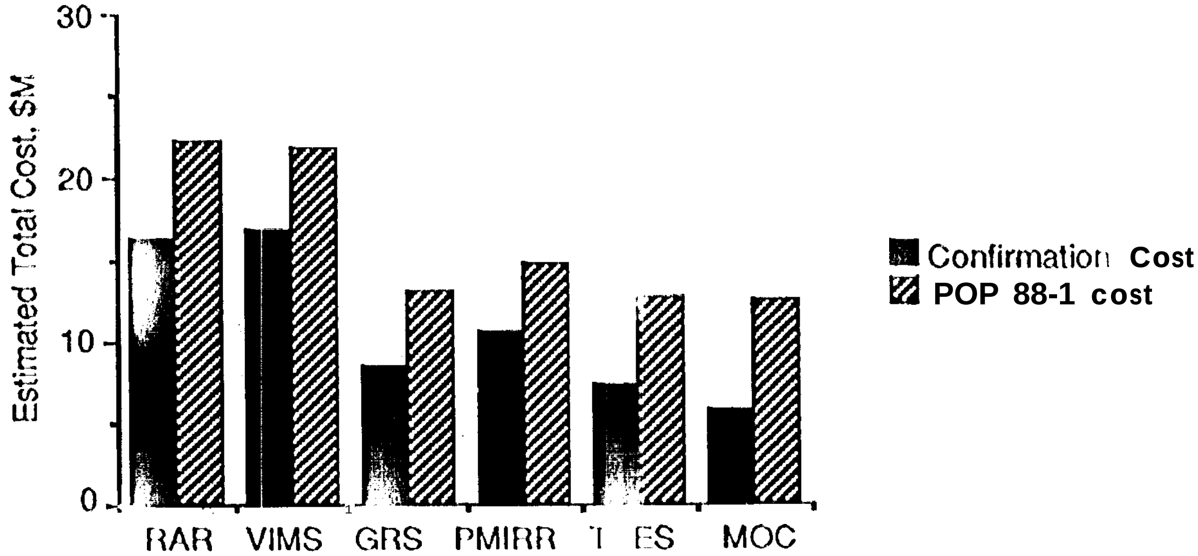

MVM = Mariner Venus/Mercury (1973)
UARS = Upper Atmosphere Research Satellite (1991)
GRO = Compton Gamma Ray Observatory (1990)
MAG = Magellan (1989)
'1'01'11X = Topography Experiment/Poseidon (1992)
GGS = Global Geospace Science (Wind and Polar)
MO = Mars Observer (1992)
GOES = Geosynchronous Operational Environmental Satellite

The result is that the SIM faces the daunting task of trying to allocate finite resources to an undetermined number of instrument development issues without the benefit of knowing whether the problems arose from an increase in instrument scope, an unanticipated technical challenge, or simply an oversight in the initial allocation of' resources.

## 2.1 Mars Observer Instrument Cost and Mass Growth

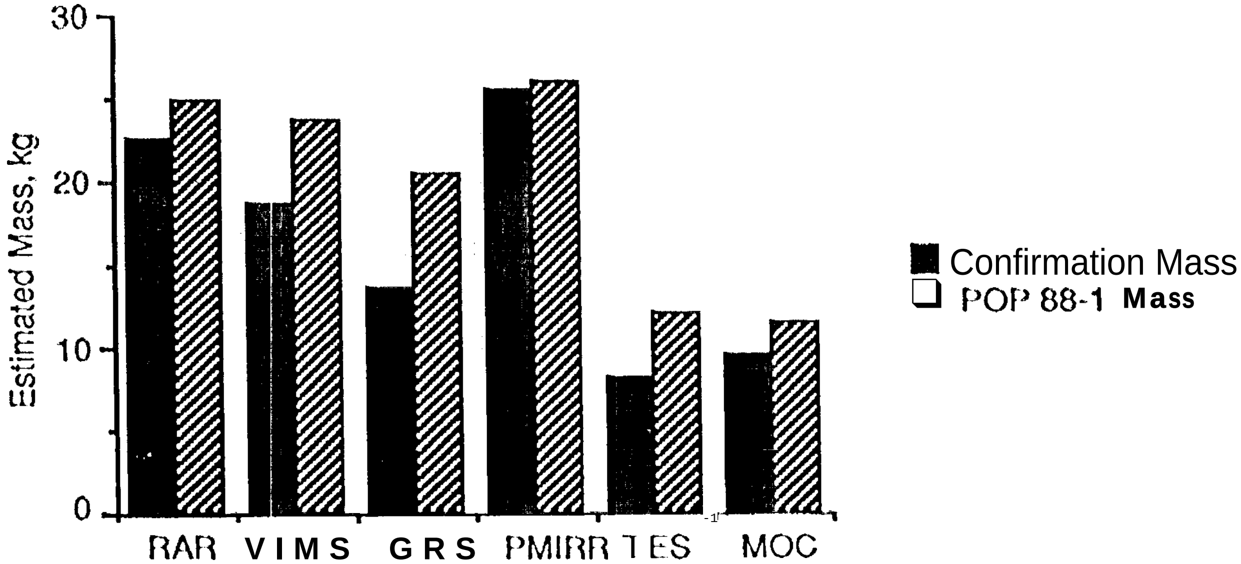
The potentially hazardous effect of instrument cost and mass growth can result in instrument descopes (in capability) m deselect ion (from the science payload). In the case of Mars Observer, the instrument cost and mass growths (see Tables ? & 3) resulted in descoping of the RADAR Altimeter & Radiometer (I<AI<) for the simpler Mars Observer Laser Altimeter (MOLA), and the de-selection of the. Visual & Infrared Mapping Spectrometer (VIMS). The Radio Science (RS) and the Magnetometer (MAG) instruments were not included in these tables as most of RS's components were part of the spacecraft's telecommunications subsystem; and MAG was the only "off-the-shelf" instrument which experienced very little cost growth.

**Table 2: Mars Observer's Instrument Cost Growth[2]**




Confirmation = Confirmation of Selected Investigations (1986)
POP = Program Operating Plan (Year - Rev)

**Table 3: Mars Observer's Instrument Mass Growth[2]**



## 3.0 DESCRIPTION OF THE CASSINI RESOURCE EXCHANGE

'1 'he ( 'assini Science Management Plan allows the instrument teams to trade resources allocated to them (mass, power, data rate and funding) in order to resolve resource issues. Specifically, the SIM would not hold reserves for instrument development difficulties, instead all reserves were allocated to the instrument teams. The instrument teams then used their allocated resources to develop their instrument. The process of initial Ic.source allocations" occurred when the project issue.(1 Letters of Agreement (LOA) to each instrument 1'1 that contained their allocation of resources. If the 1'1 signed the 1.0A, they accepted the agreement and the allocation.

During the course of development, if an instrument could not meet their LOA, they would become candidates for dc.scope.s or cancellation. Table I shows the LOA structure. Notice that the LOA identifies the instrument's mass, peak power, and peak data rate allocation as well as the funding profiles for its development. All LOAs were signed by the 1'1 and the Cassini Project Manager. The next step in the process was to design a system for trading resources.

LETTER OF AGREEMENT

This Letter of Agreement (LOA) between the Cassini Project and the Principal Investigator (PI) for the, Cassini OPTICAL investigation is for the conduct of that investigation during the Development Phase (1 October 1989 to 15 November 1 W/).

A. The ]'] agrees to:
Perform the services and provide. the deliverables as specified in Reference 1 within the resource profiles.....

B. Resource Profile

Mass Allocation: 36.21 kg

| Allocations by Operational Mode | Peak Power | Peak Data Rate. |
|---|---|---|
| Mode 01<S | 32.5 w | 6.() kbps |
| Mode RADAR | 19.5 w | 0.() kbps |
| Mode RSS | 19.5 w | 0.() kbps |

Funding Profile Allocation (Real Years $k)

| Hardware | FY90/1 | FY92 | FY93 | FY94 |
|---|---|---|---|---|
| GSFC | 1161 | 3239 | 4004 | 7504 |
| NASA HQ | 50 | 103 | 111 | 133 |
| Science | | | | |
| GSFC - Smith | 124 | 76 | 0 | 0 |
| J]'] .- Jones | 5 | 38 | 27 | 28 |
| Cent ingency | o | 0 | 0 | 0 |
| Total | 1340 | 3456 | 4142 | 7665 |

**Table 1: Structure of a Letter of Agreement**

In order to trade this many interrelated resources, an organized exchange was designed and implemented. The exchange allows instrument teams to submit bids (offers to exchange one set of resource amounts for another set of resource amounts) that all participants can view and counter with other offers, or accept the stated bid. Two interesting features of this exchange that cannot be found on any other organized exchange[a] are:

1. Package bids: These are orders that allow participants to tie demands together. Specifically, portfolios or *packages* of resources can be offered. For example, if an instrument team requires a minimum amount of watts in several operating modes, a bid of 1 watt in mode A and 1 watt in mode B and 1 watt in mode C in exchange for $12K in FY95 and $13K in FY96 funds would be possible. These allow for all or nothing and partial fulfillment of bids as stated by the participant.

2. Smart system to execute chains: Given the variety of resources and small number of participants, bilateral trading may not suffice. Specifically, several participants may be needed to complete a trade. This phenomena is referred to as a "lack of coincidence of wants." When one participant wants power for mass and another wants mass for funding, they would need another participant to complete the *chain* who would be willing to trade funding for power. This system will find such combinations if they exist.

Since no such system has been used before, the project allowed for pre-testing of the system using experimental methods in economics (see Ledyard et al. (1994) for details of this method)[3]. The tests revealed that the system was feasible and would allow teams to find chains and execute trades in an efficient manner. In particular, the research used a simulation with real human participants and found that all possible trades were executed.

### 3.1 Cassini Trading History

The Cassini Resource Exchange is a computerized multi-dimensional barter system that resides on the Internet. As a point of history, it was the first "real" trading system that used the Internet as the communication network. Although IDEA futures was in existence prior to the Cassini Exchange, it did not trade in real resources, only "play" money (See Reference 4). The Cassini Resource Exchange design has been modified and is now being used to trade Emission Credits in the Southern California RECLAIM program (see the website http://www.Opendoor.com/acemkt/Opendoor.html).

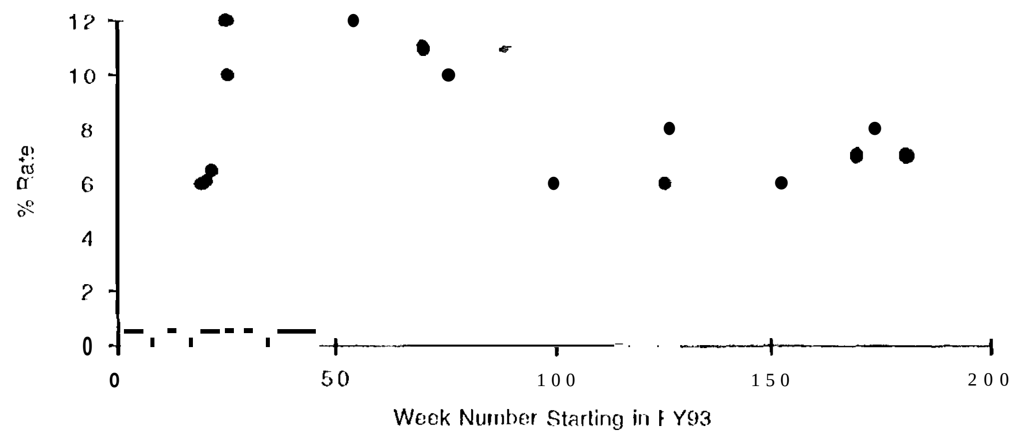
While the Cassini Resource Exchange is computerized, it is a very thin market (few participants and low volume) and participants rarely activate the system from their computers. Instead, participants communicated by e-mail or phone calls to the market coordinator who entered bids and trade information into the system and relayed that information via e-mail to participants.[b]

[a] Two notable exceptions are the portfolio trading systems run by NetExchange (see the website http://www.Opendoor.com/ace-mkt/Opendoor.html for information) and POSIT (see the website http://www.itg.com/)

[b] The market coordinator was essentially a graduate student at Caltech who on occasion checked the system, entered bids and sent e-mail to participants describing the current bids.

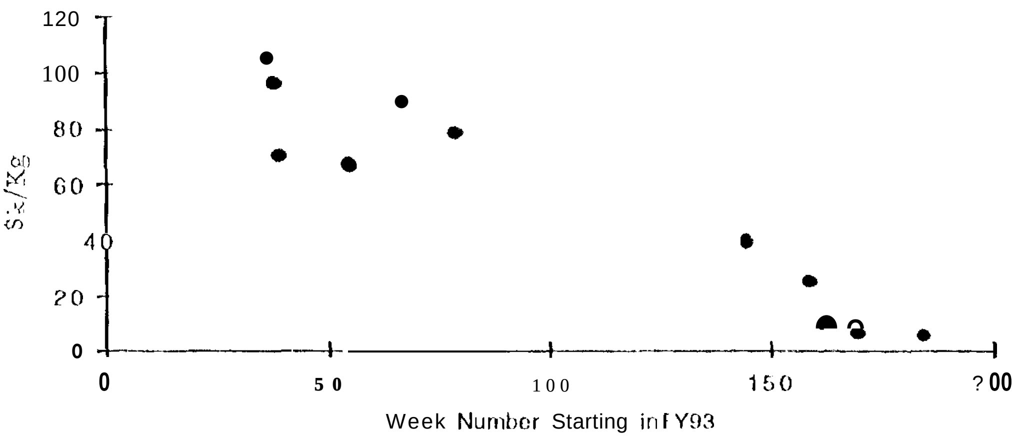
During the early history of the trading system (late 1993 to early 1995), bidding and trading were brisk. To date, there have been 29 trades with all but two trades involving money and mass. We will call trades of current fiscal year (FY) funds for future FY funds money market trades. In Figure 1, we show the activity of money market trades from the beginning of FY93 to present. The figure shows the implied interest rate between trades of current year funding for future year funding. For example, a trade at the beginning of the fiscal year of $200K in return for $212K in the next fiscal year would be seen as a 6% rate on the graph. In all, there were 16 contracts with over 4 million dollars in funds traded in the money market at an average rate of 8.475%.

**Figure 1: Money Market Activity**




In the mass market, current and future year funds were traded in return for kilograms of mass. Figure 2 shows the trades that occurred in the mass market. The trades are listed in $k per kilogram. In this figure we see the most dramatic price changes with mass price falling from a high of $ 105K in the early part of the project to a low of $5K per kilogram near instrument completion. The market turned out to have an abundance of mass so that instruments did an

**Figure 2: Mass Market Activity**



excellent job of managing their mass allocations. This has not been the history of flight projects, with mass being a very dear commodity near the project completion. Indeed, when the system was first proposed, several participants thought that mass prices would be very high with no one being able to afford mass if they ran into difficulties. This has not been the case. There have been 11 contracts with over 12 kilograms exchanged.

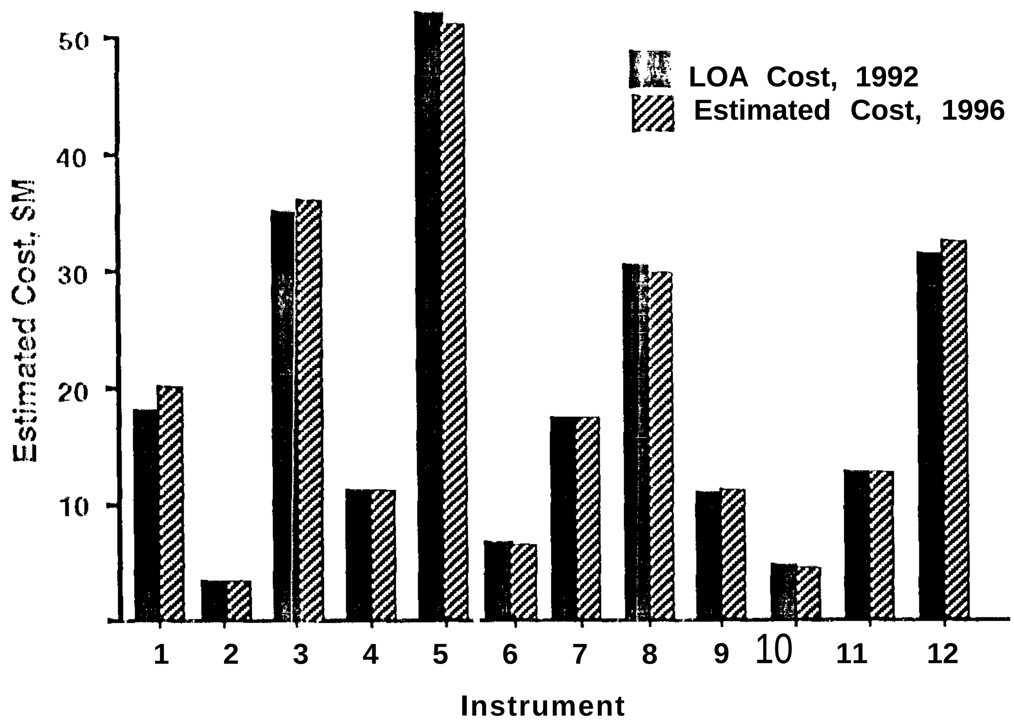
Recall that power (peak power in Watts) and data rate were designated by operational mode. That is, there are 6 space.craft operational modes that identify when an instrument will be on taking data. If an instrument required more power, it needed to obtain power in all the operational modes in which that increased power was required. This is a much more complex commodity and broaches the operational portion of the mission. As such, not much activity was registered for these commodities. Very few bids were tendered for power and only two trades occurred. These trades had 2. watts of power traded across five operational modes at a price of approximately $20K/watt.

Data rate (kbps across operational modes) was not well understood by participants and did not include storage possibilities. No trades were. made for this resource. In fact, not a single bid was tendered.

3.2 Cassini Instrument Cost and Mass Growth

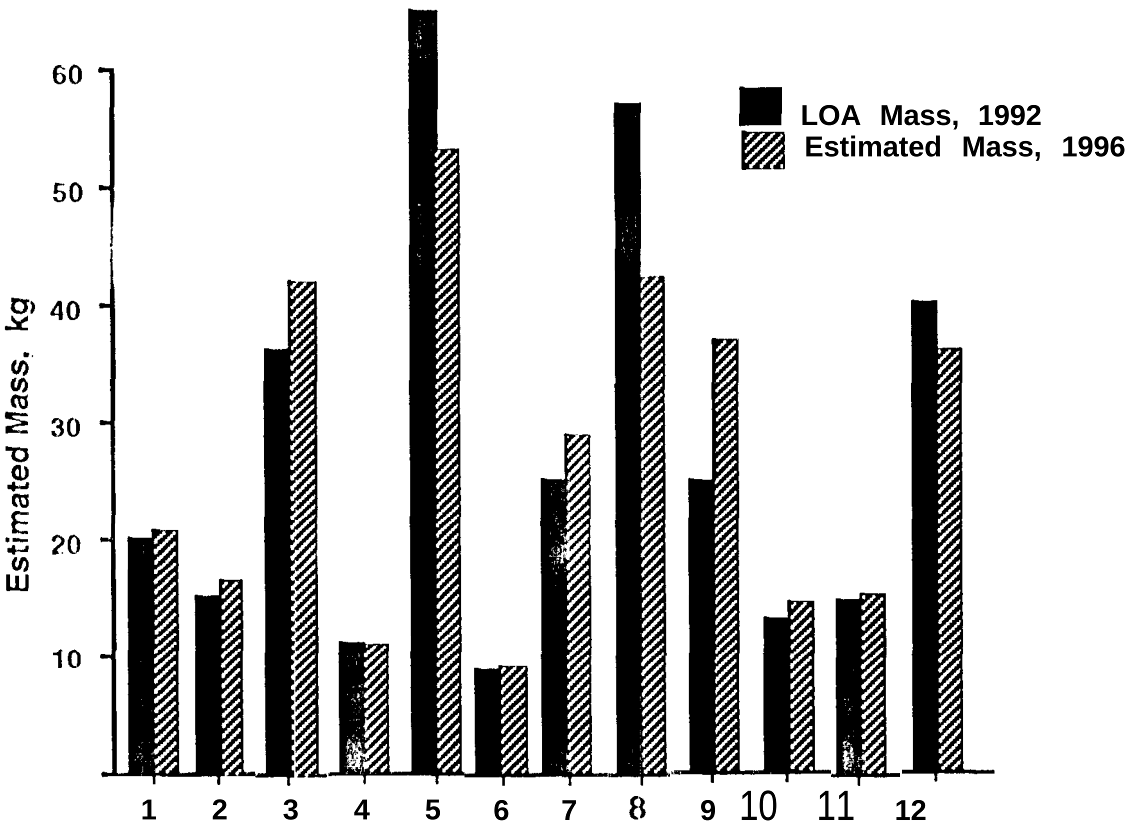
Tables 4 & 5 show the Cassini instrument cost and mass growth for the four-year period between the signing of the LOA in 1992 and the Management Monthly Report, dated 1996 June. Instrument names were withheld until final instrument deliveries, which are expected 1996 July 15.

**Table 4: Cassini's instrument Cost Growth**[6]



Instrument cost growth across all twelve Cassini Orbiter science instruments averaged less than 1%. 1 'ive of the investigations actually had decreased in cost. 'J'able 5 Snows an average instrument mass growth of slightly more than 4%, with four investigations requiring less ma ss for their Flight Model than was allocated to them in their LOA.

'J'able 5: Cassini's Instrument Mass Growth




It is anticipated that all twelve orbiter science investigations will be included on Cassini with no descopes of instrument capability.

### 3.3 A Cassini Mass Auction

One of the more unusual trades involved the Radio & Plasma Wave Subsystem (1<1'WS). In this case, the RPWS electric antennas had to be moved from the end of the Magnetometer Boom to the spacecraft basebody for spacecraft stability reasons. Moving the antennas to the basebody was a new spacecraft requirement, but would cost the PI either 14 kg of mass plus $300 k for the. thicker 1 - 1/8" diameter antennas or zero mass plus $626 k for the new 3/4" antennas.[5]

The Cassini Spacecraft Office had mass but no dollars to alleviate the problem. The resolution was that the Project held a mass auction. Since RPWS desired the thicker antennas, the plan was to sell $326 k of mass to make up the difference in cost between the two RPWS options. The auction accepted "blind" bids from the PIs. That is, each 1'1 who desired additional mass submitted a bid for X kg at $Y/kg. The bids were opened by the Project and arranged in descending order according to the highest $Y/kg bid. Mass was sold until $326 k was raise.d.

Results from the auction revealed that 10 bids requesting **20.4** kg **were** submitted. The average bid price per kilogram of mass was $46 k. The Project sold 4.634 kg at an average price of $70.35 k/kg. The auction was viewed as "quite successful" and was only possible because the. 1'1s were in control of their resources.

## 4.0 CONCLUSIONS

Past approaches for allocating resources to 1'1s always resided in the Project office.. Though the approach has continued to improve with each mission, the challenges of the system remained. The S1 M had to allocate a limited amount of resources to PIs as problems arose. This provided the wring incentive to the instrument developers. It rewarded instrument teams for developing instrument problems early. This approach also forced the SIM to make educated guesses about the source Of the instrument problems. There were no metrics to help determine if the problem resulted from an increase in instrument scope, an unanticipated technical challenge, or simply an oversight in the initial allocation of resources. Finally, once the SIM exhausts his resources, instruments that encountered additional difficulties were either descoped or de-selected from the mission.

The Cassini Resource Exchange removed the responsibility of solving instrument development issues from the SIM and placed it back on the 1'1s themselves. Research indicates that few missions, if any, had resources available after instrument development to return to the Projc.et, as was the case with Cassini.

The exchange system did have its problems. As the system was designed, there was no connection between Development and the Operational phase of the mission. If an instrument had a problem late in Development and the remaining instruments were built, there were no incentives to help the struggling investigation. The LOA did state that residual resources would revert back to the Project after Flight Model delivery, but in most cases this may be too late to help the unfortunate investigation. 11 is recommended that if future missions use this system, a mechanism be put in place that straddles the Development and Operational phases of the mission.

On a final note, the. success of the Cassini Resource Exchange has prompted Champollion, one of the two comet landers attached to the Rosetta Mission, to consider using the system to manage its power and data volume.

## 5.0 REFERENCES


1. Science Systems Contract Study, Final Report, CSP Associates, Inc., Vol. 1, p. 43

2. Polk, C., *Mars Observer Project History*, JPL D-8095, Jet Propulsion Laboratory, Pasadena, California, 1990 December.

3. Ledyard, J. O., Porter, D., Rangel, A., "Using Computerized Exchange Systems to Solve an Allocation Problem in Project Management," *Journal of Organizational Computing*, Vol. 4 (3), 1994, pp. 271-296.

4. Hanson, R., "Could Gambling Save Science? Encouraging an Honest Consensus", *Social Epistemology*, 9:1, 1995 Jan, pp. 3-33.

5. Fawcett, W. G. to PIs and Team Leaders, JPL Memorandum re: Mass Auction Results, Jet Propulsion Laboratory, Pasadena, California, 1993 May 17.

6. Fawcett, W. G., Cassini Monthly Management Report, JPL Internal Document, 1996 June 16.



The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.