SMD Cost/Schedule Performance Study

Summary Overview

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Study Charter (*revised from Nov 2006*)

- **Study Objective:** Evaluate the cost/schedule performance record of selected SMD flight projects to determine:
  - Key drivers of cost/schedule performance, and
  - Implementation approaches that enhance performance of SMD missions.
- **Approach:**
  - Select a subset of current projects that span SMD disciplines, size classes and experience base. This subset constitutes the Baseline data set.
  - For each project, collect a detailed performance history of cost, schedule and technical data by key milestones – the *Project Milestone Performance History (PMPH).*
  - Interview the Project Manager and other key staff members to collect narrative description to compare with and explain the detailed history data.
  - Collect existing data from other sources and prior studies. This additional data constitutes the Supplemental data set. The Augmented data set consists of the Baseline data augmented by the Supplemental data set. This terminology will be used throughout.
  - Characterize cost/schedule drivers for each project.
  - Identify cross-project trends in cost/schedule performance.
  - Develop findings and conclusions from project analysis and cross-project trends.
  - Recommend actions/approaches to ensure successful performance of future projects.
- **Products:**
  - Interim Reports and Midterm Report.
  - Final Report - presentation and narrative.
  - Detailed *PMPH* data in readily accessible electronic template formats.

SMD Projects Included in the Baseline Set

- Baseline projects were selected in collaboration with HQ managers; SMD gave final approval to the set.
- Baseline projects were selected to balance several factors:
  - Select from current portfolio.
  - Cover all SMD programs.
  - Cover all mission size classes.
  - Include various management institutions and PI-led missions.
  - Where possible, leverage existing data sources and prior study team experience.
- Final set of 15 Baseline projects balances these factors with available resources and the time needed to set up and conduct interviews, and to perform the data collection and analysis for the cost/schedule performance assessment.
- Limitations for data collection (all data for all milestones was not available) required some trends to be investigated with less than 15 Baseline projects.

Initial Project List for Cost/Schedule Study

SMD Division	Projects Selected
Earth Sciences	CloudSat
	ACRIMSAT
	Aqua
	Terra *
Heliophysics	RHESSI
	STEREO
Planetary Sciences	CONTOUR
	Deep Impact
	New Horizons
	MESSENGER
	MER
	MRO
Astrophysics	GALEX
	Swift
	Chandra
	Spitzer

** The initial list was reduced because of difficulty in:*
- *arranging interviews with PM and team*
- *finding and collecting available PMPH data.*

For these reasons, the Terra mission was removed from further consideration in the study (with SMD concurrence).

SMD Projects Included in the Supplemental Data

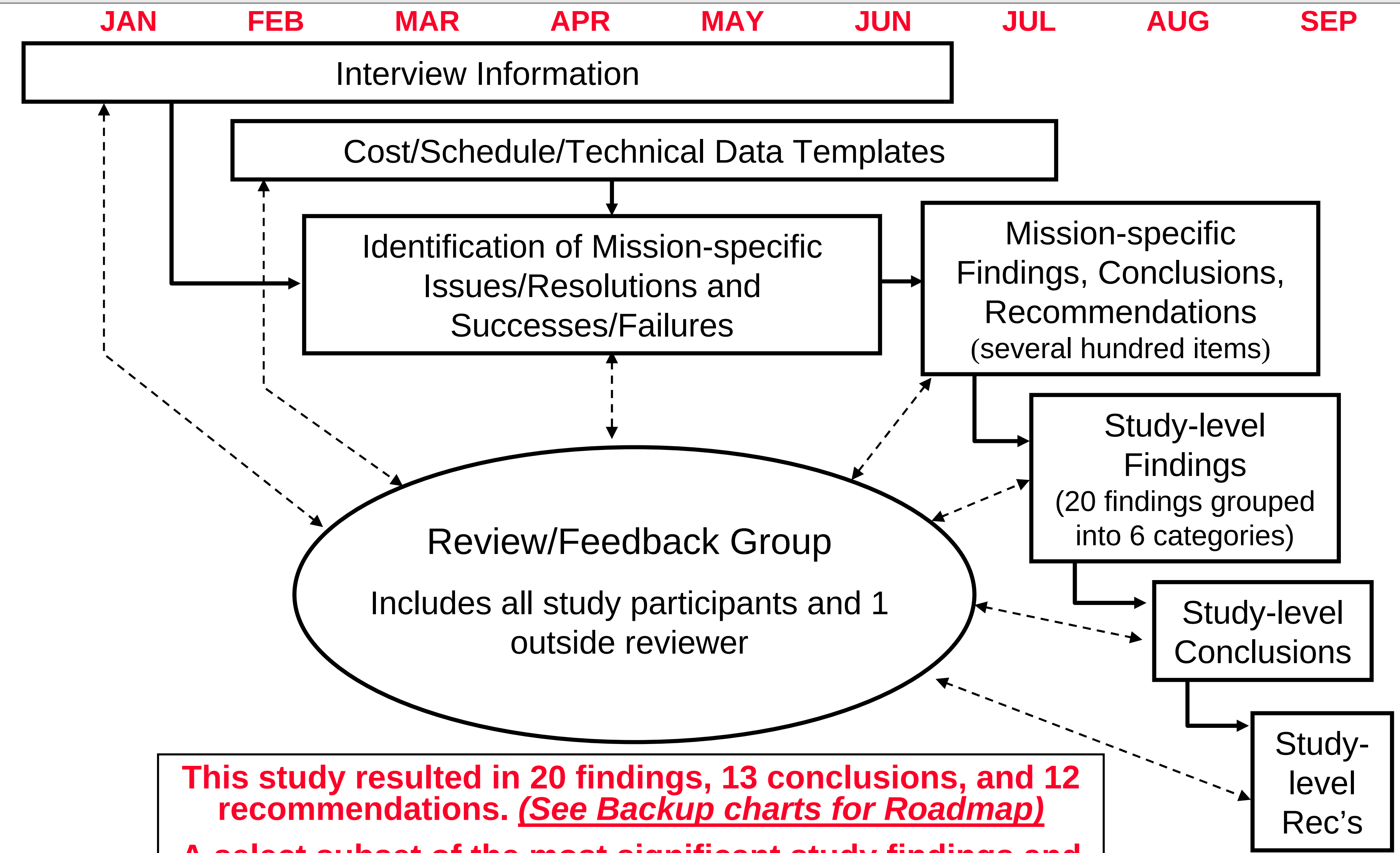
- In response to a request from NASA HQ, the study team mined additional sources of previously compiled project cost and schedule data. The goal was to determine if a larger mission set would significantly alter the findings derived from the baseline mission set. A total of *9 mission data sets* were added. *Interviews were not conducted for these missions.*

- **Data Selection Criteria**
  - Supplemental data used must be comparable to data collected for the Baseline mission set.
    - Cost and schedule data must be available from milestones prior to, or including, CDR as well as at launch in order to evaluate cost and schedule growth.
    - Cost data must be available at sufficient detail, i.e. Development, Launch Services and Operations.
  - Primary data source was the 40-mission data set used for the IEEE Paper #1545. Of the 40 mission data sets:
    - 17 data sets did not include cost and schedule data prior to CDR.
    - 3 data sets did not included sufficient cost detail.
    - 12 missions were already included in the current baseline mission set.
    - The remaining 8 data sets were added along with corresponding data from the Dawn mission.

- **Missions added:**
  - Near Earth Asteroid Rendezvous (NEAR)
  - Genesis
  - Wide Field Infrared Explorer (WIRE)
  - Wilkinson Microwave Anisotropy Probe (WMAP)
  - Gravity Recovery and Climate Experiment (GRACE)
  - Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO)
  - Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED)
  - Gravity Probe B (GP-B)
  - Dawn

- **The Augmented data set consists of Baseline data plus Supplemental data.**

Approach to Developing Recommendations

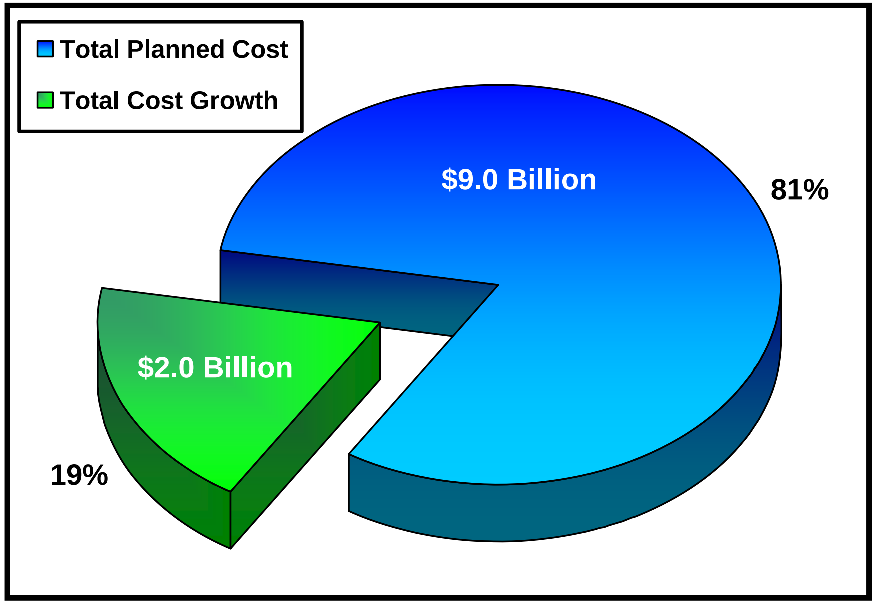


This study resulted in 20 findings, 13 conclusions, and 12 recommendations. *(See Backup charts for Roadmap)*

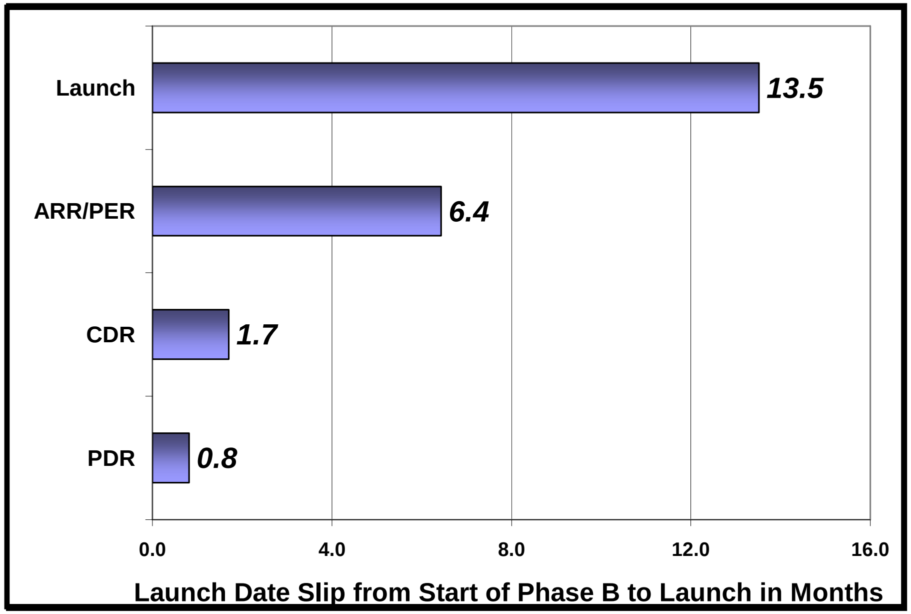
A select subset of the most significant study findings and recommendations are summarized in the following charts

Findings, page 1 of 6

- **Cost history data for 21 of the 24 projects studied shows cost growth.**
  Total cost growth from Phase B start to Estimate-to-Complete (ETC) @ Launch for all projects studied represents a combined impact of $2.0 Billion to SMD's mission portfolio.

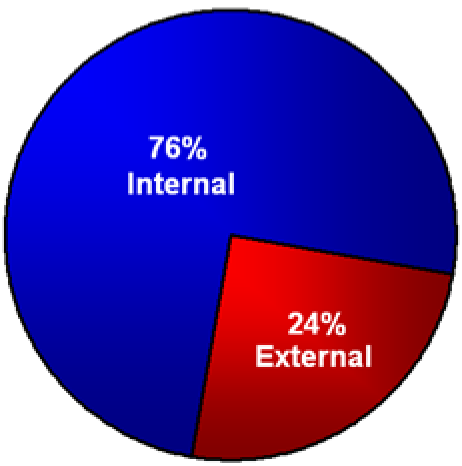


- **Schedule history data indicates schedule slips for 19 of the 24 projects studied.**
  This includes delays from all sources (externally imposed replans as well as slips from delays internal to the project). The delays ranged from 5 to 42 months.



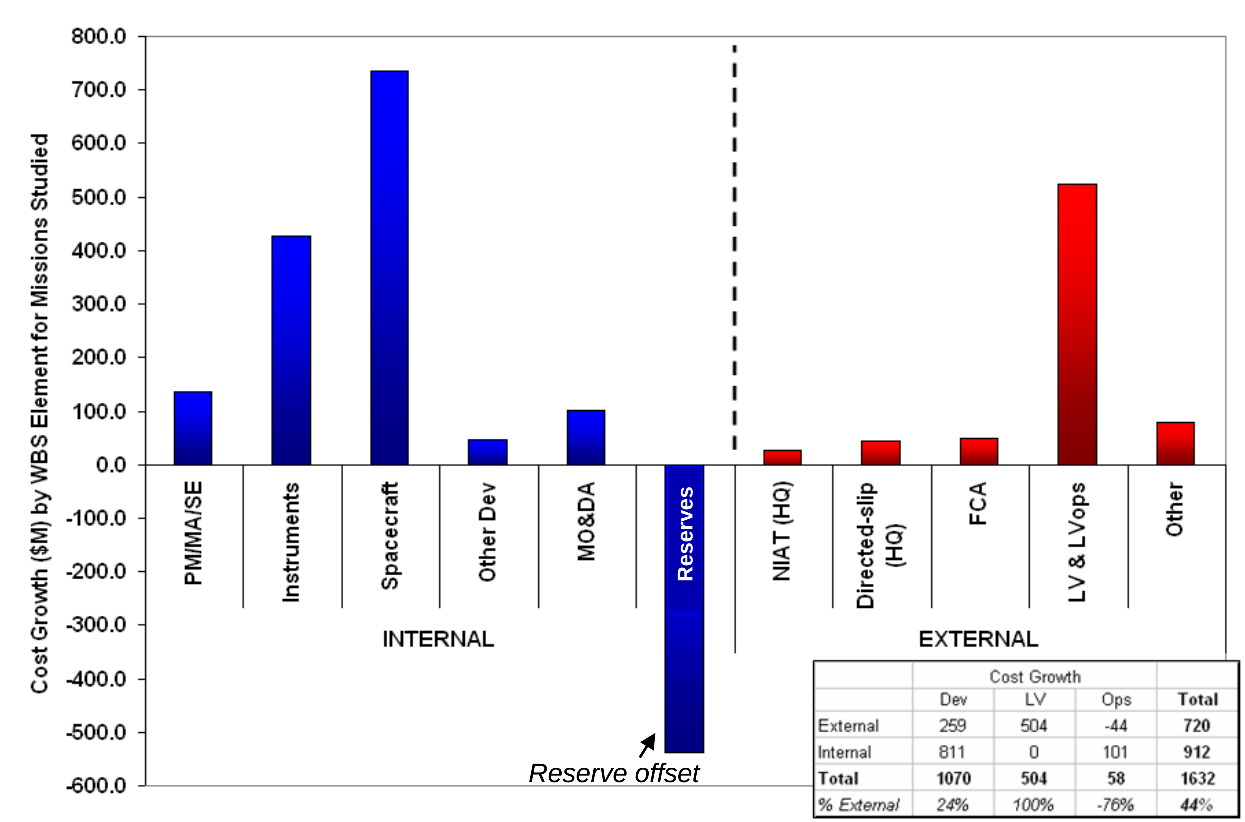
Findings, page 2 of 6

- **Data analysis of the 21 projects with cost growth indicates 24% of the overall development cost growth (excluding the launch vehicle) is from External impacts (outside project's direct control), with the remaining 76% of cost growth attributable to factors controlled internally by the project.**
  - Internal and External impacts can both produce significant cost growth. While Internal impacts appear larger than External impacts, some of the Internal cost growth may result from the indirect effects of an External impact.



- Excludes Launch Vehicle

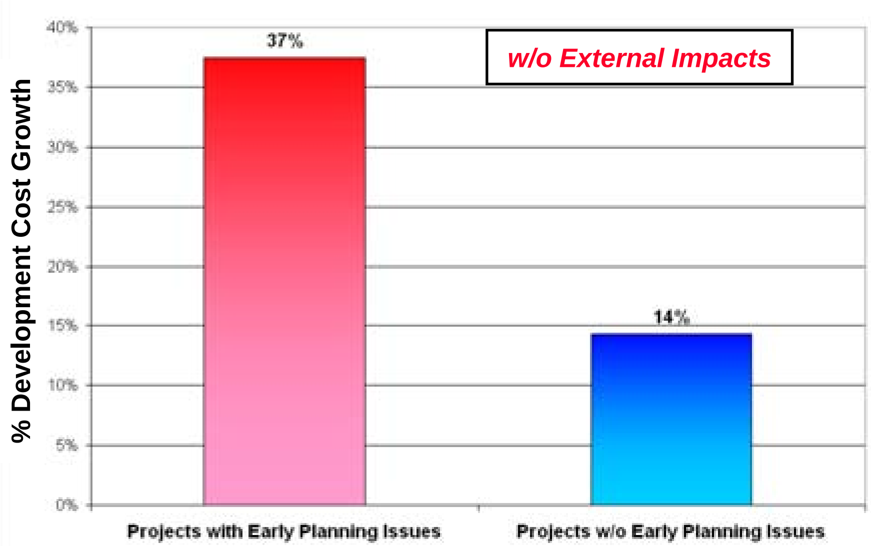
- Internal includes offset from applying cost reserves



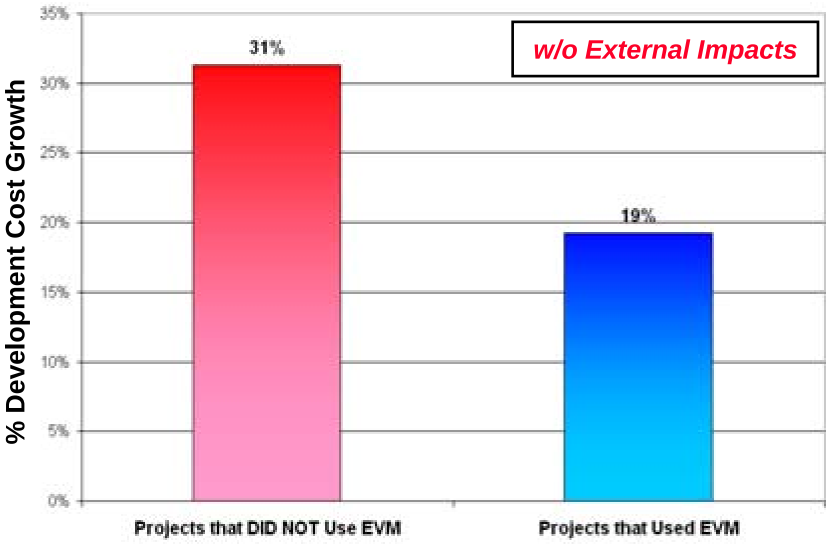
	Cost Growth			
	Dev	LV	Ops	**Total**
External	259	504	-44	**720**
Internal	811	0	101	**912**
Total	**1070**	**504**	**58**	**1632**
% External	*24%*	*100%*	*-76%*	*44%*

- **Interview comments by eight projects cited early planning deficiencies as a significant source of development problems (underestimates, inexperience, inadequate early technology investment, and/or design heritage that was not realized).**

  Analysis shows projects with early planning deficiencies experienced more than twice the development cost growth (w/o External impacts) vs. projects with adequate early planning.



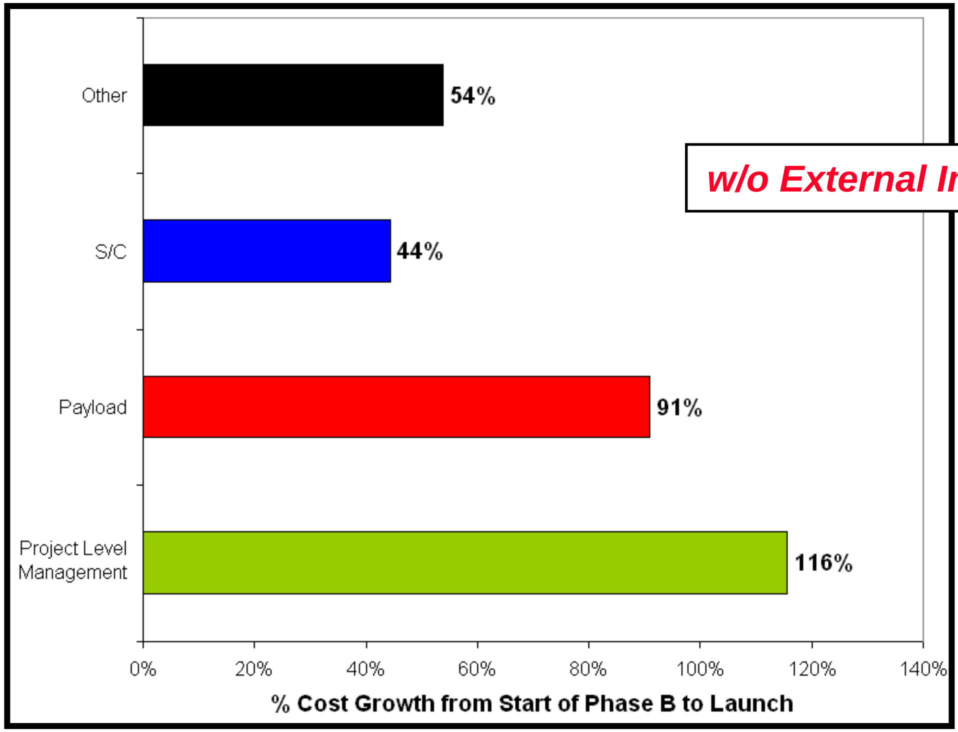
- **The four projects that reported using Earned Value Management (EVM) as a management tool show lower average growth in development costs compared to projects that did not use EVM.**

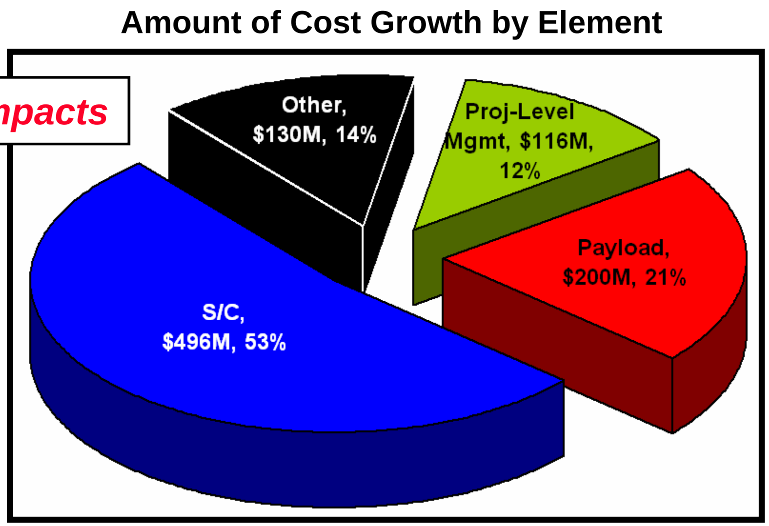


Findings, page 4 of 6

- **For the 21 projects with cost growth studied, average percent cost growth for science instruments (91%) is more than twice the growth for flight systems (44%).**
  Instrument cost growth due to design changes also affects spacecraft costs.

- **On a percentage basis, average cost growth is highest for the WBS elements covering project-level management functions (project management, mission assurance, systems engineering, etc.).**
  Although project management functions typically account for only about 10% of total cost, an average growth of 116% (excluding external impacts) is still large enough to impact the project's cost position.

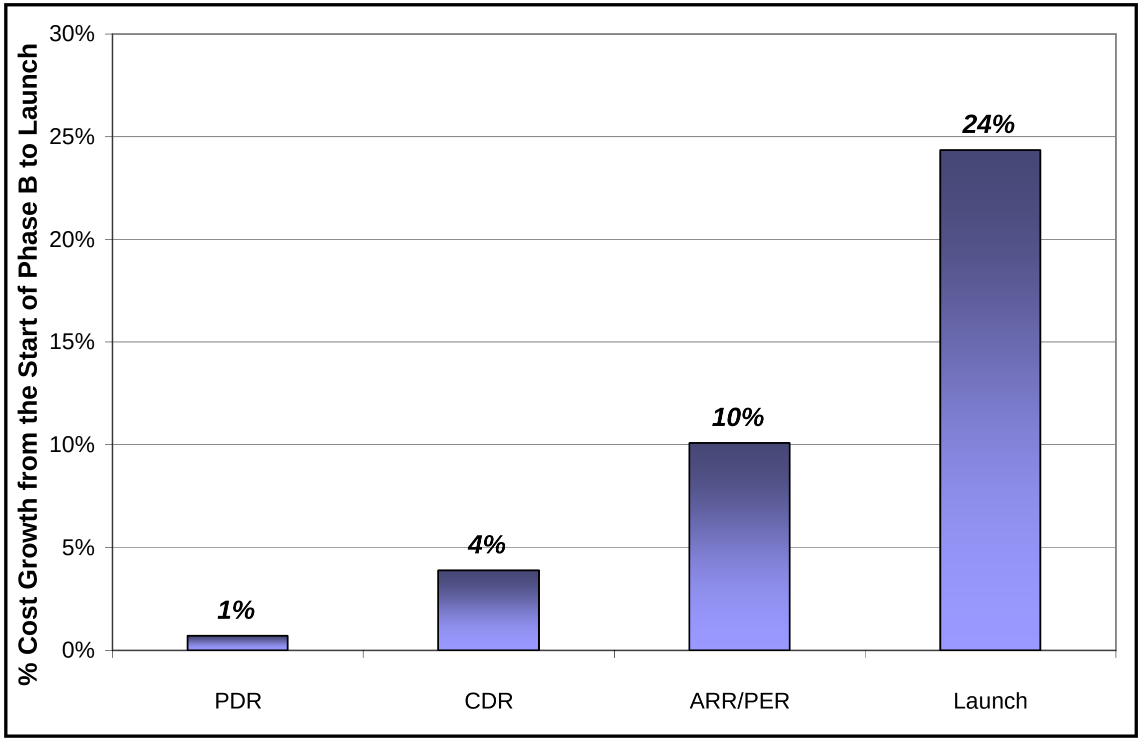




Findings, page 5 of 6

- **Fifteen of the 21 projects with cost growth show a substantially increased rate of internal cost growth after CDR.**

  Excluding external impacts, cumulative average cost growth to CDR is 4%, but this grows to 24% by launch. So 83% of this growth occurs after CDR.



For the projects in this study:

- ❑ **There is no discernable correlation between planned cost reserve level and actual cost performance (Fig. 1);**
- ❑ **There is no strong correlation between the percent of funds spent up to CDR and actual cost performance (Fig. 2); and**
- ❑ **Although adequate Phase B funding is a necessary condition for project success, it is not sufficient to ensure good overall cost performance (Fig. 3).**

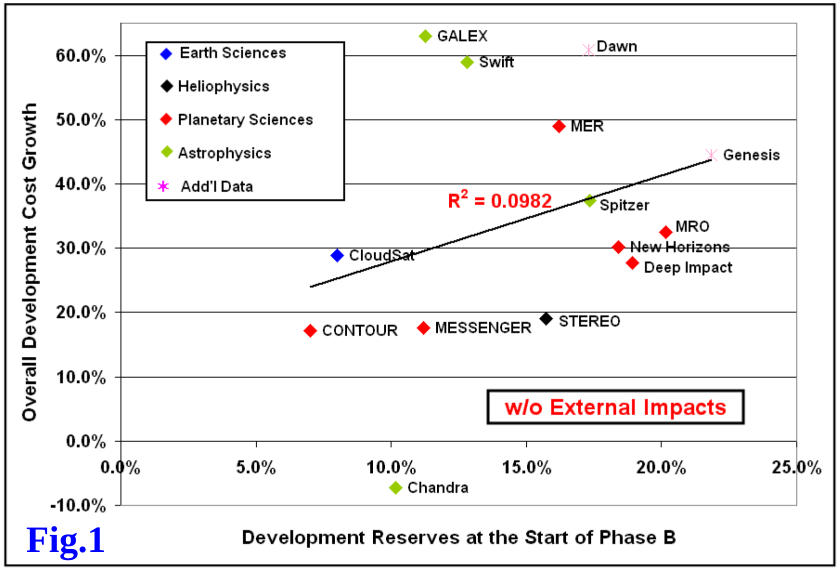


Fig.1

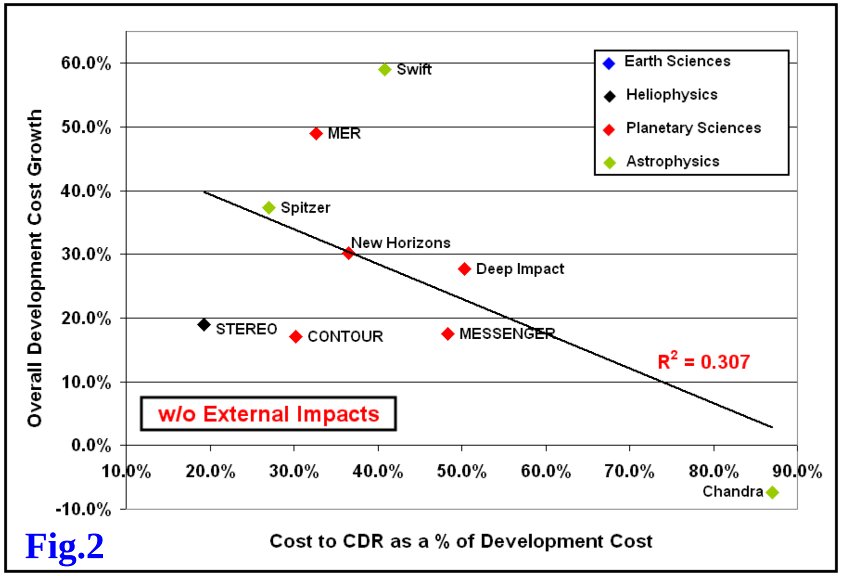


Fig.2

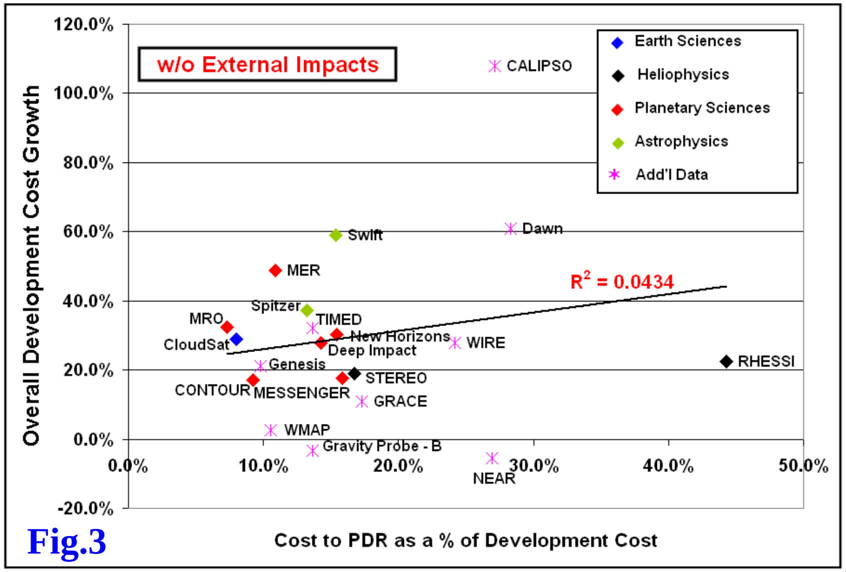


Fig.3

Recommendations, page 1 of 4

Cost Growth & Schedule Slips

- SMD should place more emphasis on detailed technical design concepts and complete implementation planning for a technical baseline early in formulation, while increasing visibility into project cost and schedule status at CDR and later milestones.
- SMD should require more rigor in the process used to generate early cost and schedule estimates and should establish a minimum set of requirements for a credible basis of estimate for mission concept costing. Projects need to be encouraged to include more conservatism in base estimates (before reserves) early in the process (proposals, CSRs, PDR) and required to carefully evaluate all key project assumptions including design heritage credits. Projects should be required to present cost and schedule status details at CDR, ARR, PER, and MRR.
- Additionally, SMD should use options for Extended Phase A and Extended Phase B whenever possible for complex projects with very attractive science allowing more time for implementation plan definition and technology development to enhance the maturity of the implementation plan before starting development and before making significant investments in other mission elements.

Recommendations, page 2 of 4

Internal & External Impacts

- ❑ SMD should work with projects as early as possible to establish a credible baseline plan that fits within the available funding with sufficient margin. Instead of waiting for projects to present a more mature plan at confirmation (end of Phase B), SMD should begin dialog at the start of Phase B (or earlier if possible) to communicate likely funding constraints that could affect implementation planning.
- ❑ SMD should keep funding profile constraints out of AOs to obtain a more credible project funding profile for initial planning. Proposed funding profiles, mission-specific launch date constraints, and program funding availability could be taken into consideration for selection.
- ❑ SMD should strive to avoid any changes/redirection, especially after PDR, to minimize cost growth from External impacts.

Earned Value Management (EVM)

- ❑ SMD should educate projects on the value and approaches for EVM, provide support for up-front investments in setting up the best system for each application as early in the development cycle as possible, and periodically verify each project is properly applying EVM throughout each mission's life cycle.

Recommendations, page 3 of 4

Project-level Management Functions

- SMD should verify projects have a credible basis of estimate for initial costing of project-level management functions. Projects should not rely on high-level percentages to capture mission-specific requirements for their concepts. SMD should require projects to allocate at least the same cost reserve percentage for project-level management functions as used for the flight hardware elements.

Instrument Cost Growth

- SMD should address weaknesses of current NASA tools for early estimation of science instrument costs and support the development of a refined approach that better captures the real cost drivers in today's environment. SMD should provide this tool to science definition teams to improve their planning capabilities. SMD should consider teaming a broad array of instrument technical experts and several cost analysts in the development of this tool.
- SMD should require project baseline instrument estimates to be based on more than analogies or parametric models as early in formulation as possible.

Recommendations, page 4 of 4

General Cost Performance Improvement

- SMD should require projects to improve the quality of early baseline cost and schedule estimates (before reserves), to include a complete and explainable basis of the estimates with corresponding cost and schedule detail, and include a level of reserves, determined by the projects, that is commensurate with the implementation risk.
- SMD should consider minimizing or eliminating blanket reserve level requirements. (For example, many AOs mandate a minimum level of reserves to be added to estimated costs.)
- SMD should hold a budget reserve at the program-level.

Study Conclusions

What are the key drivers affecting cost/schedule performance for SMD projects?

Internal Factors

Over-optimism early in formulation – Implementers are driven by pressures to maximize science per dollar to enhance attractiveness prior to authority to proceed. Combined with typical early planning deficiencies (underestimates, inexperience, design heritage not captured), the resources required are understood only as the project matures. Baselining project costs too early can lead to cost growth and schedule slips from deficiencies in the early plans. Costs cannot be accurately baselined without a thorough definition of design and schedule.

Instrument development complexity – Design and implementation plans early in formulation typically lack detail and often fail to identify some of the technology or development challenges. Also, spacecraft cost growth can be caused by instrument design changes, late instrument deliveries, and instrument problems encountered during I&T.

External Factors

Launch service issues – Growth in this area, which is not in the project's direct control, account for almost one third of the $2.0B growth across the Augmented data set.

Unstable or inadequate initial funding profile – These problems distract the project management team from the real challenges of implementing the project to work on replanning efforts.

Study Conclusions

What practices contribute to improved cost/schedule stability for programs and projects?

The SMD projects evaluated in this study have experienced cost growth and schedule slips over early budget plans despite having what was considered to be:

1. Ample reserves
2. Best project managers
3. Best management practices
4. Highly qualified and dedicated core teams of engineers and managers
5. Extensive and increased scrutiny by external reviewers

The study team concludes that all of these attributes are necessary, but not sufficient, for meeting cost and schedule performance goals. The study team recommends that SMD ensures that every current or contemplated project is supported by:

1. A **stable external environment** of fixed requirements, funding, and launch services.
2. **Sufficient program-level budget reserves** to address impacts from changes external to the projects.
3. A requirement that each project's activities during formulation focus on **in-depth understanding and disciplined development of the baseline**, which includes the technical mission implementation as well as the cost estimate, funding profile, and the resource-loaded schedule for getting to launch.

Past Studies Offer Similar Recommendations

- **NASA'S Project Management Study (1980)** concluded that one of the most significant contributors to cost and schedule growth was inadequate definition of technical and management aspects. Cited in GAO Report GAO/NSIAD-93-97, Dec 1992.
- **NASA'S Roles & Missions Report (1991)** documented need for increased emphasis on technological readiness and requirements on the front end of a program. Cited in GAO Report GAO/NSIAD-93-97, Dec 1992.
- **GAO Report GAO-04-642, May 2004**: "… the programs we reviewed failed to follow key cost-estimating processes, including developing and documenting full life-cycle cost estimates, summarizing estimates according to the current breakdown of work to be performed, conducting an uncertainty analysis, performing an independent review of contractors' cost estimates, and later using earned value management (EVM) to assess progress."
- **Acquisition of National Security Space Programs (Young Report) May 2003**: "The space acquisition system is strongly biased to produce unrealistically low cost estimates throughout the acquisition process." – A critique of defense programs that parallels NASA experience.
- **Humboldt Mandell's Lessons Learned From Previous NASA Management Studies (Aug 2002)**:
  - Keep requirements fixed: once requirements are stated, only relax them; never add new ones
  - Don't start a program until cost estimates and budget availability match
  - Minimize or eliminate government imposed changes

"NASA has known these principles for many years.
Implementation has been resisted by the culture." – H. Mandell

Backup Charts

Past Studies on Related Topics

"AO History Summaries of PI–Led Missions," Final Study Presentation to Orlando Figueroa by SSO, August 8, 2005.

"Cost History Summaries of PI–Led Missions – FY06 Edition," by SSO, December 7, 2006.

Bitten, Robert E., David A. Bearden, Norman Y. Lao, Timothy H. Park, "The Effect of Schedule Constraints on The Success Of Planetary Missions," Fifth IAA International Conference on Low-Cost Planetary Missions, 24-26 September 2003

Bitten, Robert E., Debra L. Emmons, Claude W. Freaner, "Using Historical NASA Cost and Schedule Growth to Set Future Program and Project Reserve Guidelines," IEEE Paper #1545, December 2006.

Bitten, Bob, Debra Emmons, Claude Freaner, "A Development Paradigm: Instrument First, Spacecraft Second (IFSS), August 14, 2007.

Jacobs, Mark, & Shawn Hayes, "Do Higher Cost Reserve Levels for Space Science Missions Ensure Good Cost Performance?", IEEEAC paper #1482, January 2006.

NASA Cost Estimating Handbook, 2006 update.

NASA Lessons Learned Database

"NASA Program Costs: Space Missions Require Substantially More Funding Than Initially Estimated," GAO Report GAO/NSIAD-93-97, December 31, 1992.

"NASA: Lack of Disciplined Cost-Estimating Processes Hinders Effective Program Management," GAO-04-642, May 2004.

"New Frontiers in the Solar System: An Integrated Exploration Strategy," Solar System Exploration Survey (the Decadal Survey), Space Studies Board, National Research Council, pre-publication copy, July 9, 2002.

Perry, Brad, Shawn Hayes and Mark Jacobs, "Cost History Summaries of PI–Led Missions: FY06 Edition," Dec 7, 2006.

Other (including non-SMD) Past Studies reviewed by J. Hamaker for findings relevant to this study:

"Constellation Program Stretch Goals Study," The Aerospace Corporation, September 2006.

"Kelly Johnson's 14 Skunk Works Rules," Lockheed Skunk Works, 1950s.

Mandell, Humboldt, "A Summary of Lessons Learned From Previous NASA Management Studies," August 2002.

"New Ways of Doing Business Survey," Space Systems Cost Analysis Group, December 1997 and September 1998, SAIC.

Sipple et al., "Surveying Cost Growth," Defense Acquisition University Review Journal, January 2004.

"Space Systems Development Growth Analysis," performed by Booz, Allen and Hamilton for U.S. Air Force, August 2002.

Strope, Donald, "ACE Lessons Learned," GSFC, July 1998.

Young, Tom et al., "Acquisition of National Security Space Programs (Young Report)," Defense Science Board, May 2003.

Findings to Recommendations Roadmap

(Items in red bold text are included in this package)

CONTRIBUTING FINDINGS	RECOMMENDATIONS
[F1] Cost Growth Across Mission Set; **[F2] Phase B to Launch Cost Growth by Mission;** **[F3] Schedule Performance by Mission;** **[F15] Post-CDR Cost Growth;** **[F19] Early Planning Deficiencies**	**[R1] Cost Growth & Schedule Slips**
[F4] Internal and External Cost Growth; **[F5]** Stable Funding	**[R2] Internal & External Impacts**
[F6] Launch Service Cost Growth Issues	**[R3]** Launch Services
[F7] Impact of Earned Value Management	**[R4] Earned Value Management**
[F8] Project-level Management Cost Growth **[F9]** Project-level Management post-PDR Growth	**[R5] Project-Level Management Functions**
[F10] Best Management Practices	**[R6]** Best Practices
[F11] Instrument & Spacecraft Cost Growth	**[R7] Instrument & Spacecraft Cost Growth**
[F12] Secondary Impacts from Descopes	**[R8]** Secondary Impacts from Descopes
[F13] Actel Field Programmable Gate Array Issue	**[R9]** Actel FPGA Issue
[F14] Spacecraft I&T Cost Growth	**[R10]** Spacecraft I&T Cost Growth
[F20] Hardware from Foreign Partners	**[R11]** Foreign Partner Contributions
[F16] Cost Reserves and Cost Performance **[F17] Phase B Funding and Cost Performance** **[F18] Funding to CDR and Cost Performance**	**[R12] Cost Performance Improvement**