Integrated Cost/Schedule Analysis – Lessons Learned on GEMS

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Abstract

NASA recently established a policy to assess the Joint Confidence Level (JCL) of a project through the creation of an Integrated Cost and Schedule Model. Implementation of the NASA JCL policy has been challenging for projects due to a variety of reasons. The Gravity and Extreme Magnetism SMEX (GEMS) Project recently completed a JCL and presented it to NASA senior leadership. Although the project did not receive a favorable decision at review, the JCL analysis product and briefing is considered one of the best the agency has seen to date.

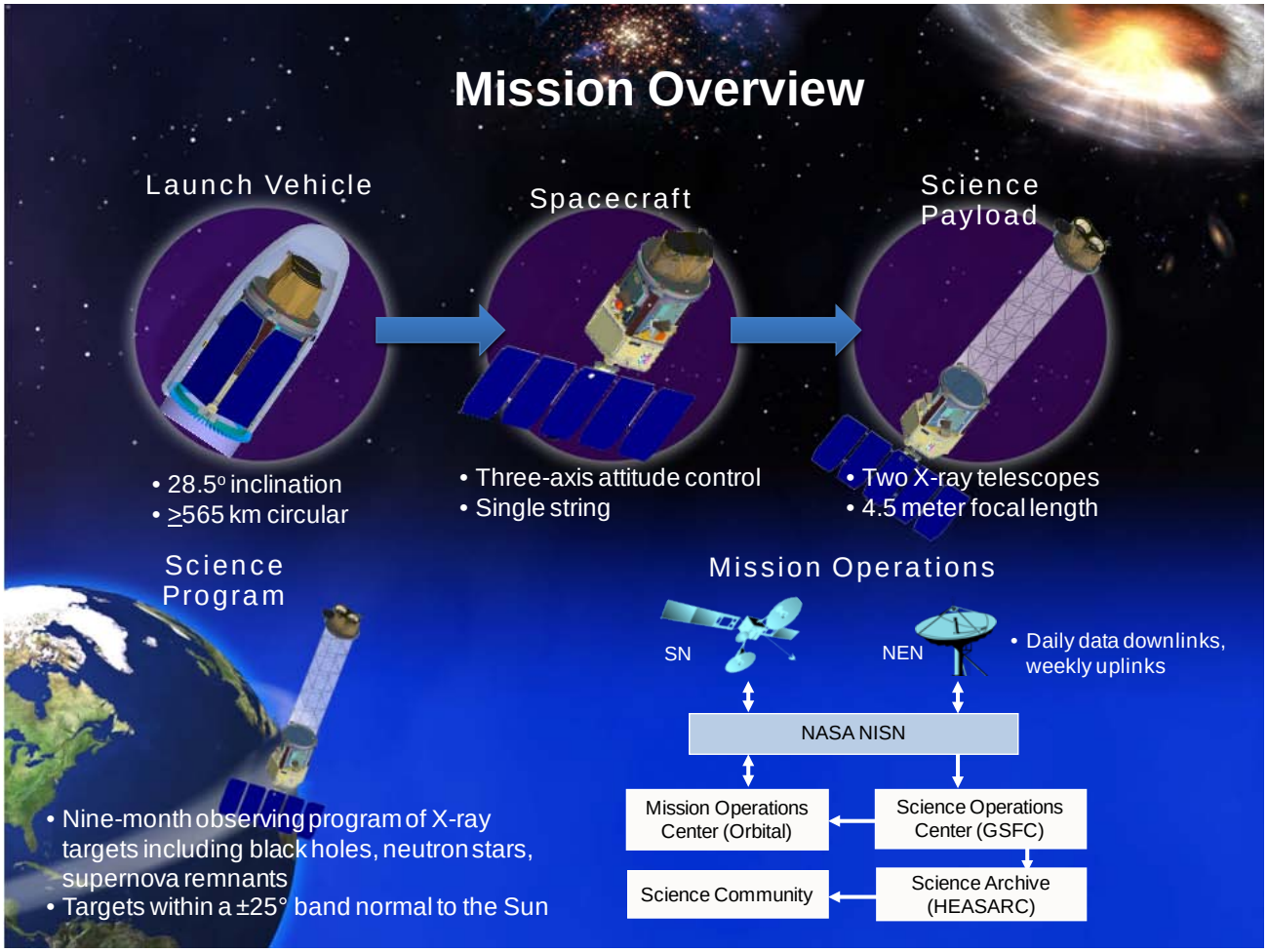
NASA's Cost Analysis Division (CAD) is actively using the analysis example in a government policy implementation working group. GEMS utilized ACEIT and JACS to complete their JCL. This presentation will provide an overview of their analysis package, discuss lessons learned in creating a JCL, and discuss the plans of the policy implementation working group at NASA.

Outline

- Gravity and Extreme Magnetism Small Explorers (SMEX) (GEMS) Overview
- GEMS JCL Methodology
- GEMS Examples of Analysis Charts
- JCL Project Perspective
- NASA CAD Policy Implementation Working Group

GEMS Overview

- GEMS is a Small Explorer (SMEX) mission that planned to conduct a unique X-ray polarization survey of black holes, supernova remnants, and neutron stars; which has never been done and cannot be accomplished by other missions.
- Planned Launch Readiness Date (LRD) of November 2014.
- The GEMS X-ray Polarimeter Instrument (XPI) achieved TRL-6 in October 2011.
- The mission Preliminary Design Review (PDR) was successfully completed in February 2012.
- KDP-C was held in May 2012. The mission was not confirmed to proceed into Phase C.



GEMS JCL Methodology

Overview – GEMS JCL Methodology

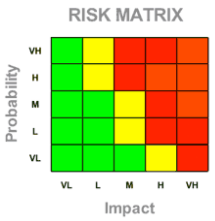
- The GEMS Project Office conducted an internal assessment of its cost and schedule to determine its overall risk posture:
  - Analyzed the project plan as depicted in the GEMS Integrated Master Schedule (IMS) and determined uncertainty on the remaining effort based on historical analogies and Subject Matter Experts (SME).
  - Reviewed the project Risk Register (5x5's) to identify and quantify the impacts if the risks were realized; these risks were added as probabilistic events to the schedule.
  - Identified that a large majority of GEMS costs are directly related to overall duration and modeled the respective costs as a function of schedule (Time Dependent Costs (TD)), thereby incorporating the underlying schedule risk into the cost risk analysis.
  - Assessed the potential range of costs and specified uncertainty to the TD burn rates and the non-TD total costs for "To-Go" costs.
  - Incorporated the cost impacts of the incorporated Risk Register.

- End results were range estimates for total GEMS costs and schedule, as well as a JCL analysis – these satisfy NASA NPR 7120 requirements.

- Data Sources:
  - IMS as of February 24, 2012
  - Funding Plan as of February 24, 2012
  - Risk Register as of February 24, 2012

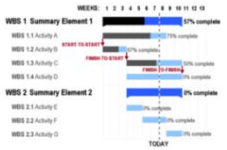
Risk, Schedule and Cost Process

Risk



Collect Risk Data → Assign Likelihood, Determine Impacts → Map to Sched Activities

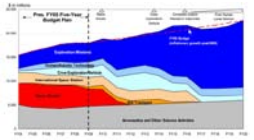
Schedule



Assess Durations

Collect Sched Related Data → Determine High-Level Flow → Generate Analysis Schedule → Update Analysis Schedule → Incorporate Uncertainty → Validate File → Run Analysis

Cost

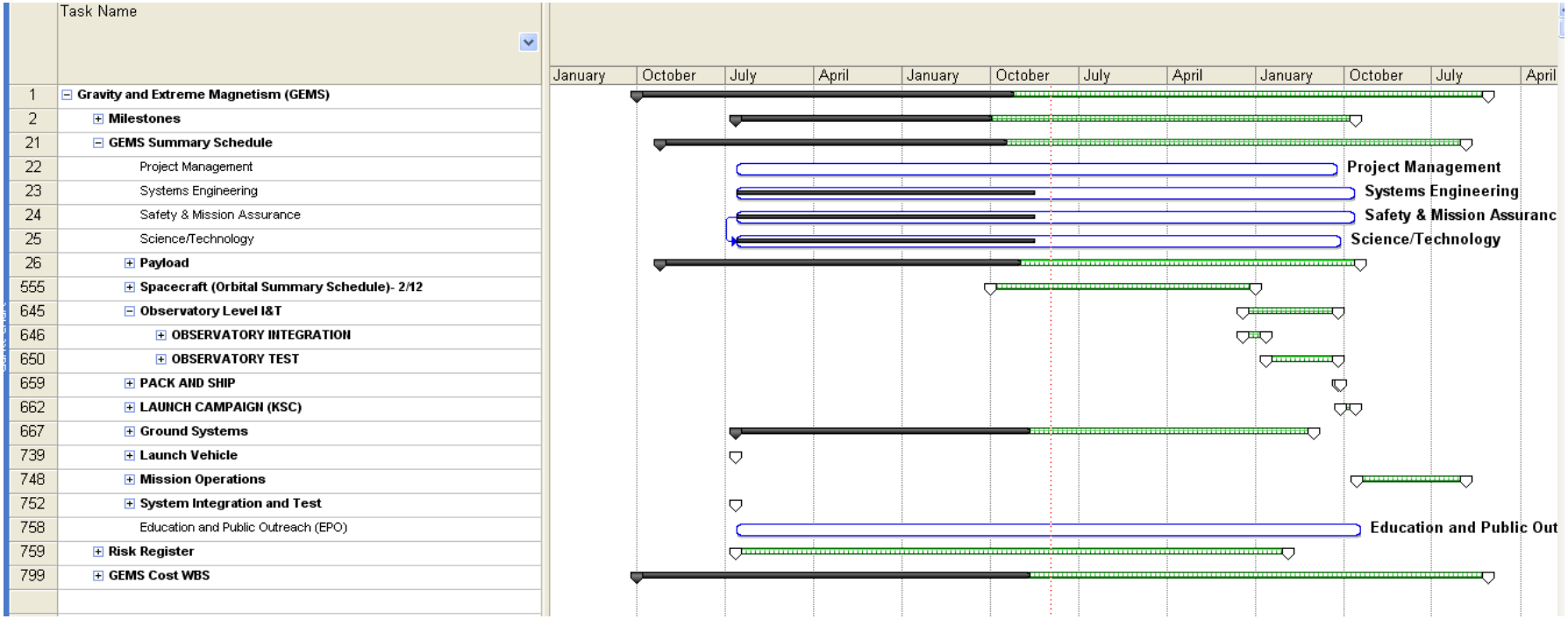


Collect Cost Data → Identify Cost Behavior (TD vs. TI) → Map to Sched Activities → Assess Cost Uncertainty

Time

Top-Level Summary Analysis Schedule

- Summary Analysis Schedule has same Top-Level flow as the GEMS management schedule, but the detail is directly informed by IMS:



GEMS Analysis Schedule Format

- Used special fields to allow tagging of file to provide linkage to source data (GEMS IMS):

Task Name	Key Lir	Task Calend	Analysis Sched IMS ID	Analysis Sched - IM ID Finish	Anlys Sched - IMS Start Da	Anlys Sched - IMS Finish Date	Analysis Schedule - IM Duration	Duration
Polarimeter Assembly	**No**	**Holidays**	**535**		**Wed 12/10/08**	**Mon 2/25/13**	**1035 d**	**1035 d**
Mirrors	**No**	**None**			**Fri 10/1/10**	**Mon 12/3/12**	**0 d**	**768 d**
Mirror Requirement	No	Holidays	7545	12872	Fri 10/1/10	Tue 8/30/11	229 d	229 d
Foils	No	Holidays	9450	1461	Tue 2/15/11	Thu 5/10/12	302 d	302 d
Structures	**No**	**None**			**Tue 6/28/11**	**Fri 10/5/12**	**0 d**	**731 d**
Mirror Housings	**No**	**Holidays**	**9468**	**9468**	**Tue 6/28/11**	**Fri 10/5/12**	**312 d**	**125 d**
Mirror Alignmer	**No**	**Holidays**	**12980**	**12980**	**Tue 6/28/11**	**Mon 8/20/12**	**279 d**	**243 d**
Connector Ring	**No**	**Holidays**	**13019**	**13019**	**Tue 6/28/11**	**Fri 5/11/12**	**210 d**	**210 d**
Thermal Shields	No	Holidays	12900	12889	Thu 12/15/11	Mon 10/1/12	191 d	191 d
Mirror Integration, T	**No**	**Holidays**	**12888**	**12888**	**Wed 4/25/12**	**Mon 12/3/12**	**152 d**	**757 d**

Identifies if it's a key link in schedule flow

Identifies IMS Start task

Identifies IMS finish task

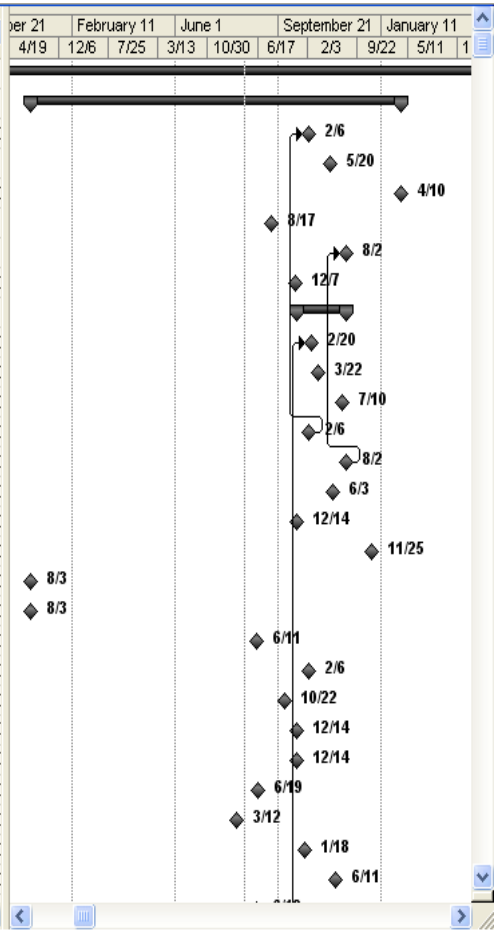
Identifies IMS reference dates for start and finish

Identifies est. duration between dates

Discrete Risk Incorporation

- Risks incorporated into schedule logic as probabilistic events:

	Name	JACS Threat ID	JACS Threat	JACS Duration Uncertainty	JACS TI Cost Uncertainty
1	**Gravity and Extreme Magnetism (GEMS)**		**0**		
759	**Risk Register**		**0**		
760	MAU Development	EXP_GEMS_MSE_0011	25	5,12,60,0,85);Correl(MSE_011=0.9)	Tri(200,500,1500,0,85);Correl(MSE_011=0.9)
761	SOC Software Development Support	EXP_GEMS_MSE_0038	10	0	1
762	3pt Shock Environment Undefined	EXP_GEMS_MSE_0043	25	i(3,5,10,0,85);Correl(MSE_043=0.9)	Tri(100,250,500,0,85);Correl(MSE_043=0.9)
763	Mirror Thermal Shield Direct Sun Damage	EXP_GEMS_MSE_0046	10	0	1
764	Final RF Frequency Pair Assignement	EXP_GEMS_MSE_0048	25		1
765	Orbital subcontractor proposal's based on RC	EXP_GEMS_PRJ_0062	25		Tri(400,600,1500,0,85)
766	**Launch Vehicle Procurement**	**EXP_GEMS_PRJ_0069**	**50**		
767	MECHANICAL (STRUCTURE) SUBSYSTI	EXP_GEMS_PRJ_0069_1	100	(5,48,60,0,85);Correl(PRJ_069=0.9)	Tri(72,143,215,0,85);Correl(PRJ_069=0.9)
768	THERMAL SUBSYSTEM	EXP_GEMS_PRJ_0069_2	100	(5,48,60,0,85);Correl(PRJ_069=0.9)	Tri(72,143,215,0,85);Correl(PRJ_069=0.9)
769	POWER SUBSYSTEM	EXP_GEMS_PRJ_0069_3	100	(5,48,60,0,85);Correl(PRJ_069=0.9)	Tri(72,143,215,0,85);Correl(PRJ_069=0.9)
770	C&DH SUBSYSTEM	EXP_GEMS_PRJ_0069_4	100	(5,48,60,0,85);Correl(PRJ_069=0.9)	Tri(72,143,215,0,85);Correl(PRJ_069=0.9)
771	RF SUBSYSTEM	EXP_GEMS_PRJ_0069_5	100	(5,48,60,0,85);Correl(PRJ_069=0.9)	Tri(72,143,215,0,85);Correl(PRJ_069=0.9)
772	ACS SUBSYSTEM	EXP_GEMS_PRJ_0069_6	100	(5,48,60,0,85);Correl(PRJ_069=0.9)	Tri(72,143,215,0,85);Correl(PRJ_069=0.9)
773	HARNESS SUBSYSTEM	EXP_GEMS_PRJ_0069_7	100	(5,48,60,0,85);Correl(PRJ_069=0.9)	Tri(72,143,215,0,85);Correl(PRJ_069=0.9)
774	USN Certification	EXP_GEMS_PRJ_0072	10		Tri(200,460,2500,0,85)
775	Orbital FFP Transition - Uincertainty	EXP_GEMS_PRJ_0085	99		LN(2250,1200)
776	XPI Cost Control due to Schedule Impacts - Ur	EXP_GEMS_PRJ_0086	25	10,20,30,5,85);Correl(PRJ_086=0.9)	Tri(500,1000,2000,0,85);Correl(PRJ_086=0.9)
777	Travel Budget Reductions	EXP_GEMS_PRJ_0087	50	ri(2,5,10,0,85);Correl(PRJ_087=0.9)	Uni(5,50,0,85);Correl(PRJ_087=0.9)
778	MAU EMI/EMC	EXP_GEMS_PRJ_0088	25	10,15,20,0,85);Correl(PRJ_088=0.9)	Tri(8,25,35,0,85);Correl(PRJ_088=0.9)
779	TOB Development	EXP_GEMS_PRJ_0089	99	10	LN(1000,500)
780	Use of Plastic parts in BRP instrument	EXP_GEMS_S&MA_0002	25	0	0
781	BRP Fe55 Safety and Transpotation Concern	EXP_GEMS_S&MA_0005	10	0	0
782	APV-25 Radiation Affects	EXP_GEMS_XPI_0002	10	Tri(1,5,90,0,85);Correl(XPI_02=0.9)	Tri(1,5,200,0,85);Correl(XPI_02=0.9)
783	Background Rejection of the ETU Polarimeter	EXP_GEMS_XPI_0007	25	Tri(5,15,65,0,85);Correl(XPI_07=0.9)	Tri(50,100,400,0,85);Correl(XPI_07=0.9)
784	Polarimeter Lifetime	EXP_GEMS_XPI_0036	25	20,40,80,0,85);Correl(XPI_036=0.9)	Tri(50,100,300,0,85);Correl(XPI_036=0.9)
785	BRP Support Costs	EXP_GEMS_XPI_0061	75	60	Tri(15,25,50,0,85)



Schedule Uncertainty Approach

- In addition to the discrete risks identified, there is general uncertainty on the estimated durations for all ongoing and future tasks:
  - Changes in the actual accomplished duration for these tasks will alter the programs' critical path and generate revised delivery and launch dates.
  - Through identifying ranges for the estimated durations, the GEMS project office can gain insight into which areas have the greatest possibility for causing a delay to the end launch date.

- GEMS classified schedule activities into four categories and developed approaches for each to determine the range estimates (uncertainty distributions); all duration activities were then correlated at 60%

Category	Description	Approach
Complete	Tasks which are 100% complete as of the analysis date	No distribution
Behind-Schedule	Tasks which should have been finished by analysis date but which are less than 100% complete	SME Low-Most Likely - High
In-Progress	Tasks which have started by analysis date but are expected to finish in the future	SME Low-Most Likely – High
Future	Tasks which have not started by the analysis date and are planned to start in the future	Historical Analogy

Cost Risk Analysis Approach

- An Integrated Cost and Schedule Model was built to directly capture schedule impacts into cost analysis:
  - Time Dependent (TD) costs based on length of schedule activities.
  - Costs phased based on schedule dates.
  - Costs and annual phasing re-calculated during each simulation run.

- Costs based on High-Level Project WBS and mapped to corresponding schedule efforts via Schedule Hammocks (an interactive link between a task signifying the start of the effort and a task signifying the completion of the effort).

- Costs analyzed and split into TD and Time Independent (TI) behavior.

- Costs broken into actual costs (through end of FY11) and cost to-go.

- Uncertainty applied to all to-go costs.

- All costs correlated at 55%

GEMS Examples of Analysis Reports

Discrete Risk Register

- Thirty Five (35) risks identified in GEMS Risk Register.

- Impacts identified and quantified for each Risk Event:
  - Likelihood of occurrence: Determined by risk register value.
  - Schedule activity impacted: Identified by project.
  - Impact range: Based on risk register value, but quantified by project.

Risk ID	Title	Risk Owner	Risk Type	Risk Impact	Action	Score	Likelihood	Consequence	Risk Statement	Schedule Impact	Low (Days)	Most Likely (Days)	High (Days)	Cost Impact	Low Multiplier	Mult Most Likely	High Multiplier	Impacted Area
EXP-GEMS-MSE-0011	MAU Development	FRANCISCO ANDOLZ	MSE	Schedule	Mitigate	4	2	2	Given that: the MAU is in development; There is a possibility that: the MAU will not be ready for GEMS mission resulting in impacts to design, cost, and schedule.					$	$	$	$	Orbital MAU, WBS 6.0
EXP-GEMS-MSE-0036	Solar Array Deployment Testing	FRANCISCO ANDOLZ	MSE	Technical	Watch	5	1	5	Given that: the GEMS Solar Array full deployment will not be tested with g-negation at the Observatory level prior to launch There is a possibility that: the solar array will not deploy properly on orbit reulting in a S/A configuration that will not generate the required power.					$ -	$ -	$ -	$ -	None - Risk is a watch. Orbital process.
EXP-GEMS-MSE-0038	SOC Software Development Support	FRANCISCO ANDOLZ	MSE	Schedule	Mitigate	2	1	2	Given that: the SOC requires more support than currently identified There is a possibility that: the SOC software development will not be ready in time to support XPI flight testing.					$ -	$ -	$ -	$ -	None - staffing already budgeted. Working to bring individual on-board
EXP-GEMS-MSE-0043	3pt Shock Environment Undefined	FRANCISCO ANDOLZ	MSE	Technical	Mitigate	6	2	3	Given that: a GEMS specific 3-pt shock environment has not been defined and indications are from a previous mission's 3pt Shock Environment There is a possibility that: the GEMS 3pt Shock Environment, when defined, will affect component qualification status and require further testing, analysis and/or waivers.					$	$	$	$	Observatory I&T; WBS 10
EXP-GEMS-MSE-0046	Mirror Thermal Shield Direct Sun Damage	FRANCISCO ANDOLZ	MSE	Technical	Mitigate	3	1	3	Given that: the melting point of thermal shield film epoxy is approximately 130 degrees C There is a possibility that: exposure to direct					$ -	$ -	$ -	$ -	None - mitigation approaches are underway as standard engineering

Uncertainty Distributions – Future Tasks

- General distribution developed and applied to all future tasks
  - Distribution based on observed schedule growth post –PDR for prior SMEX and Medium-Class Explorers (MIDEX) projects:

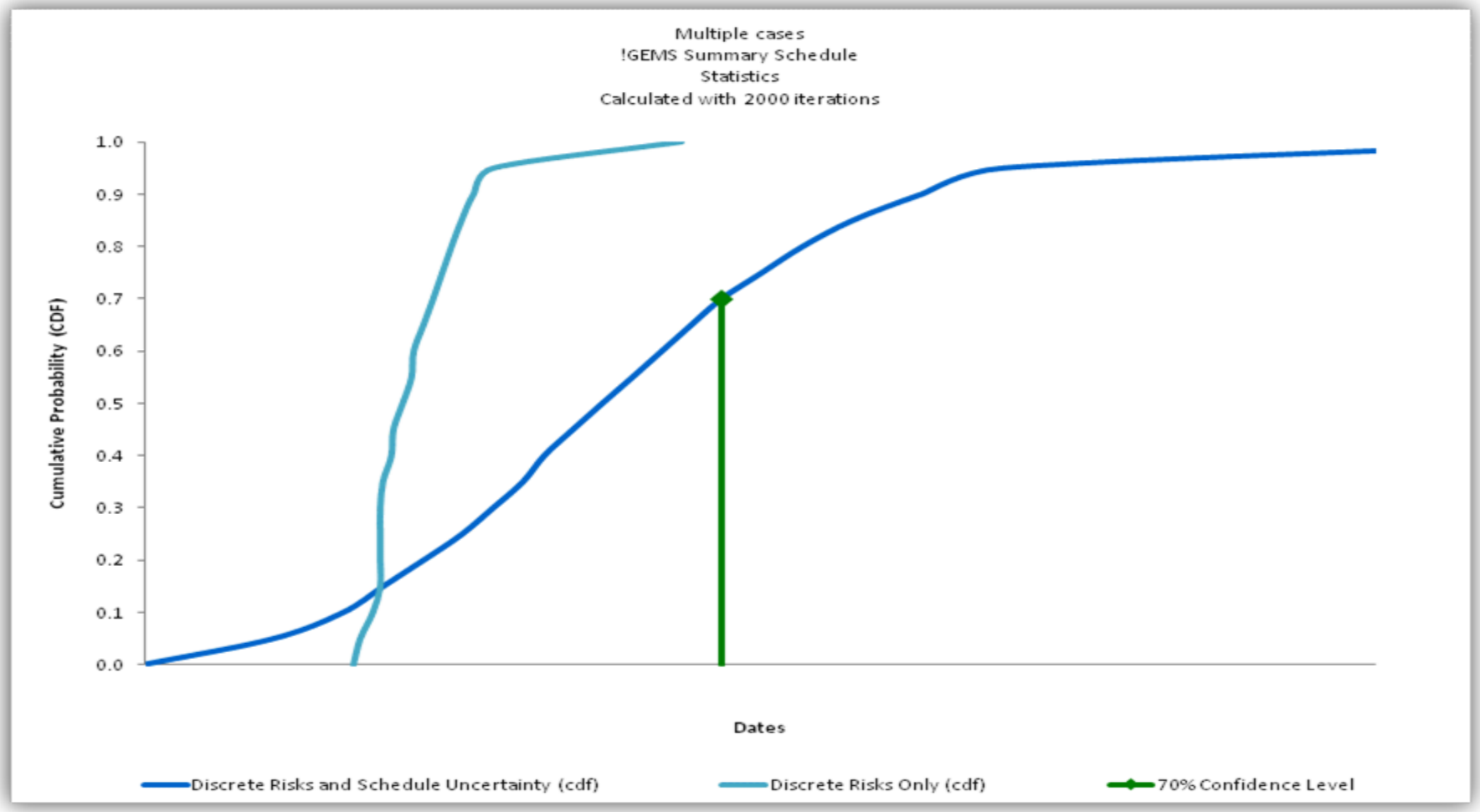
		SRR -Launch (Months)				Growth from PDR	%/Growth
	Project	SRR	PDR	CDR	Actual		
SMEX	Sampex	37	37	37	38	1	2.70%
	FAST	44	44	44	67	23	52.27%
	GALEX	37	37	37	56	19	51.35%
	AIM	40	40	40	47	7	17.50%
	IBEX	33	33	33	37	4	12.12%

- Analysis identified Lognormal distribution with average schedule growth of 23% as best fit for historical data:

	Sample	LogNormal	Normal	Triangular
Mean	1.2266	1.2304	1.2266	1.2301
StdDev	0.2345	0.2266	0.2202	0.2121
CV	0.1912	0.1841	0.1796	0.1724
Low	1.0000			0.8653
Mode		1.1704	1.2266	1.0000
High	1.5227			1.8250
Standard Error of Estimate		0.0953	0.1012	0.0964

Impact of Duration Uncertainty to GEMS Launch Schedule

Schedule uncertainty inputs drive the schedule risk finish date results



TD Cost Uncertainty Distributions

- Risk Band approach (Low, Medium, High) used to specify TD burn rate uncertainty distributions.

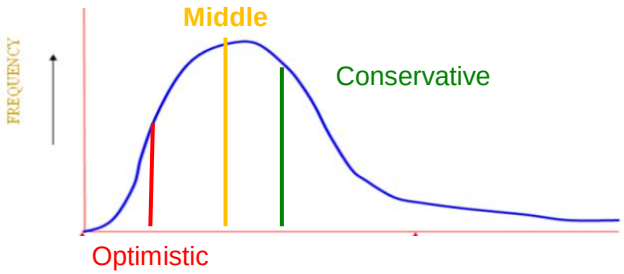
- To-Go Costs evaluated and assigned a risk band.

WBS Item	TD "To-Go" Costs $M	Risk Band
Mission System Engineering		Med
Polarimeter Assembly		High
Mirrors		Med
Mechanical/Structures		Med
Telescope Electronics		High
HVPS		High
Instrument I&T		High
Systems Engineering		Med
Mechanical		Med
CD&H		Med
ACS		High
FSW		High
System I&T		High

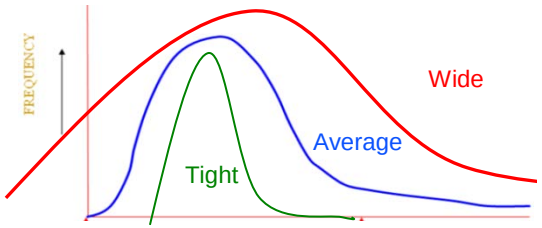
WBS Item	TD "To-Go" Costs $M	Risk Band
Project Mgmt		Low
Mission Assurance		Low
Science & Data Analysis		Low
Instrument Mgmt		Low
Instrument System Engineering		Low
Contamination		Low
Electronic Parts & Screening		Low
Material/Processes		Low
Harnessing		Low
Thermal Control System		Low
Post Delivery Support		Low
HQ-Instrument Technical Support		Low
PMO		Low
Flt Assurance		Low
Production Planning		Low
Thermal		Low
EPS		Low
Comm		Low
Harness		Low
GSE		Low
Flight Ops		Low
GSFC-Ground System Management		Low
GSFC-Mission Operations Center (M		Low
GSFC-Science Operations Center (SC		Low
GSFC-Tracking Network		Low
Education & Public Outreach		Low
Student Experiment		Low

TI Cost Uncertainty Distributions

- Risk Band approach with skew (bias) and spread used
  - Bias (Estimate Confidence Level)



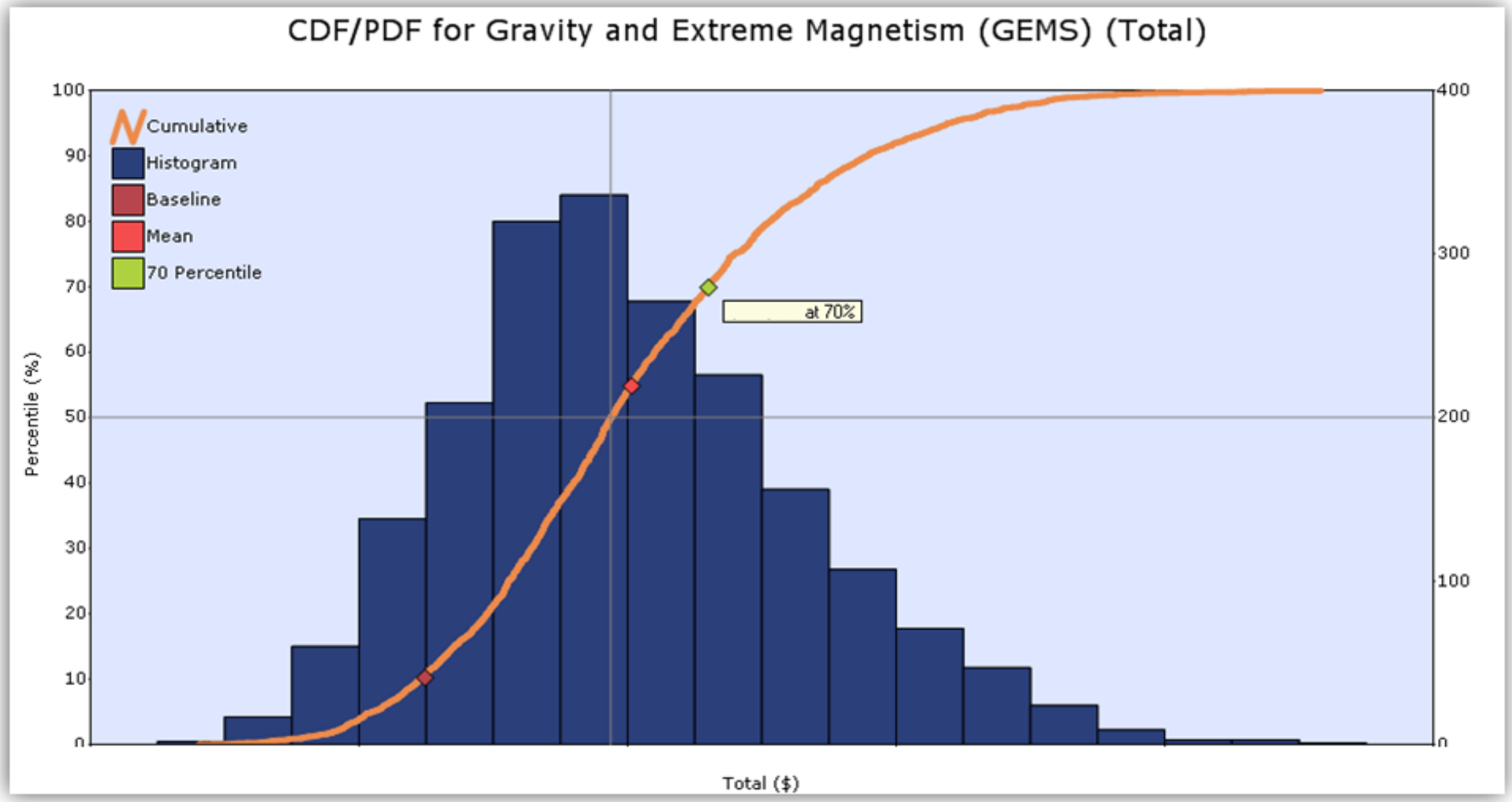
  - Spread (Estimate Variability)



WBS Item	TI "To-Go" Cost	Risk Band
Project Mgmt		Cons_Tight
Science & Data Analysis		Cons_Tight
Instrument Mgmt		Cons_Tight
Instrument System Engineering		Opt_Avg
Contamination		Cons_Tight
Electronic Parts & Screening		Mid_Tight
Material/Processes		Cons_Tight
Polarimeter Assembly		Opt_Wide
Mirrors		Opt_Wide
Mechanical/Structures		Opt_Avg
Telescope Electronics		Cons_Tight
HVPS		Opt_Avg
Harnessing		Cons_Tight
Thermal Control System		Cons_Tight
Instrument I&T		Cons_Tight
Post Delivery Support		Cons_Tight
PMO		Cons_Tight
Systems Engineering		Mid_Avg
Mechanical		Mid_Avg
Thermal		Mid_Tight
EPS		Opt_Tight
CD&H		Opt_Avg
Comm		Mid_Avg
ACS		Opt_Avg
Harness		Cons_Tight
GSE		Cons_Tight
GSFC Flt Ops-Science Operations		Mid_Avg
GSFC-Mission Operations Center		Cons_Avg
GSFC-Science Operations Center		Mid_Avg
GSFC-Tracking Network		Cons_Tight
System I&T		Opt_Wide
Education & Public Outreach		Cons_Tight
Student Experiment		Cons_Tight

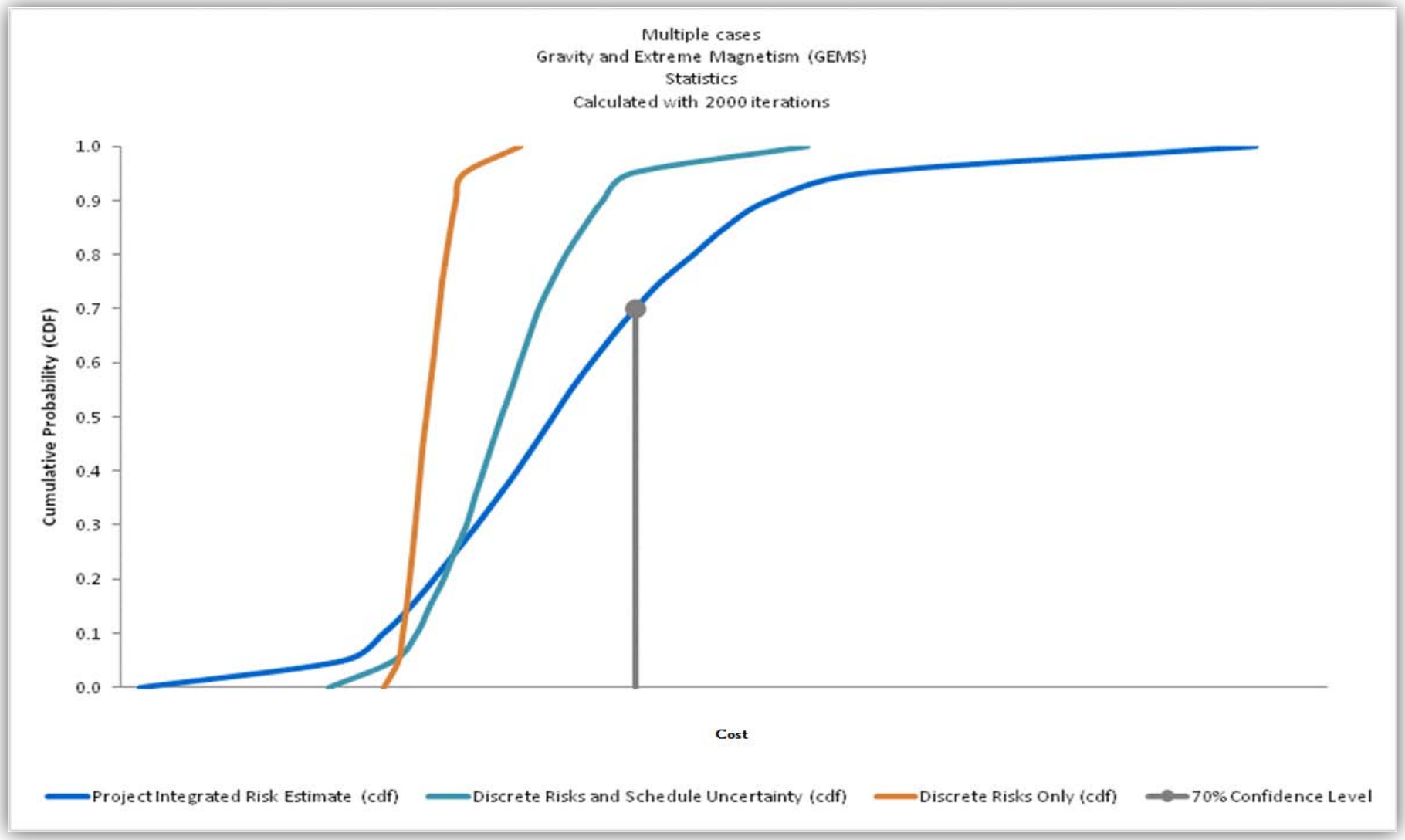
Cost Risk Analysis Results

- 70% Cost Confidence Level with Cost/Schedule Uncertainty and Discrete Risks is $M:

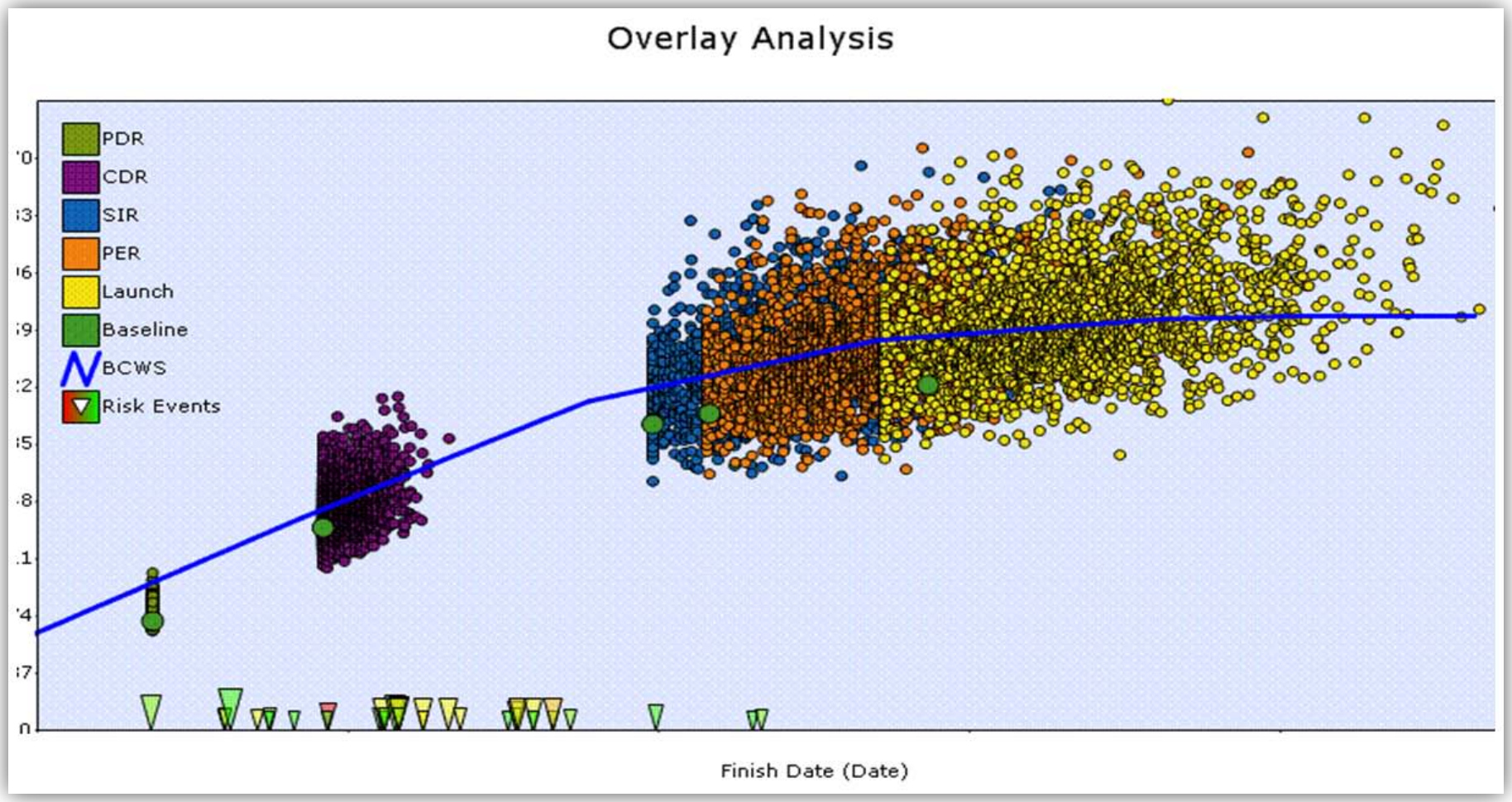


Cost Uncertainty Analysis

- Schedule Uncertainty is a larger contributor than Discrete Risks:

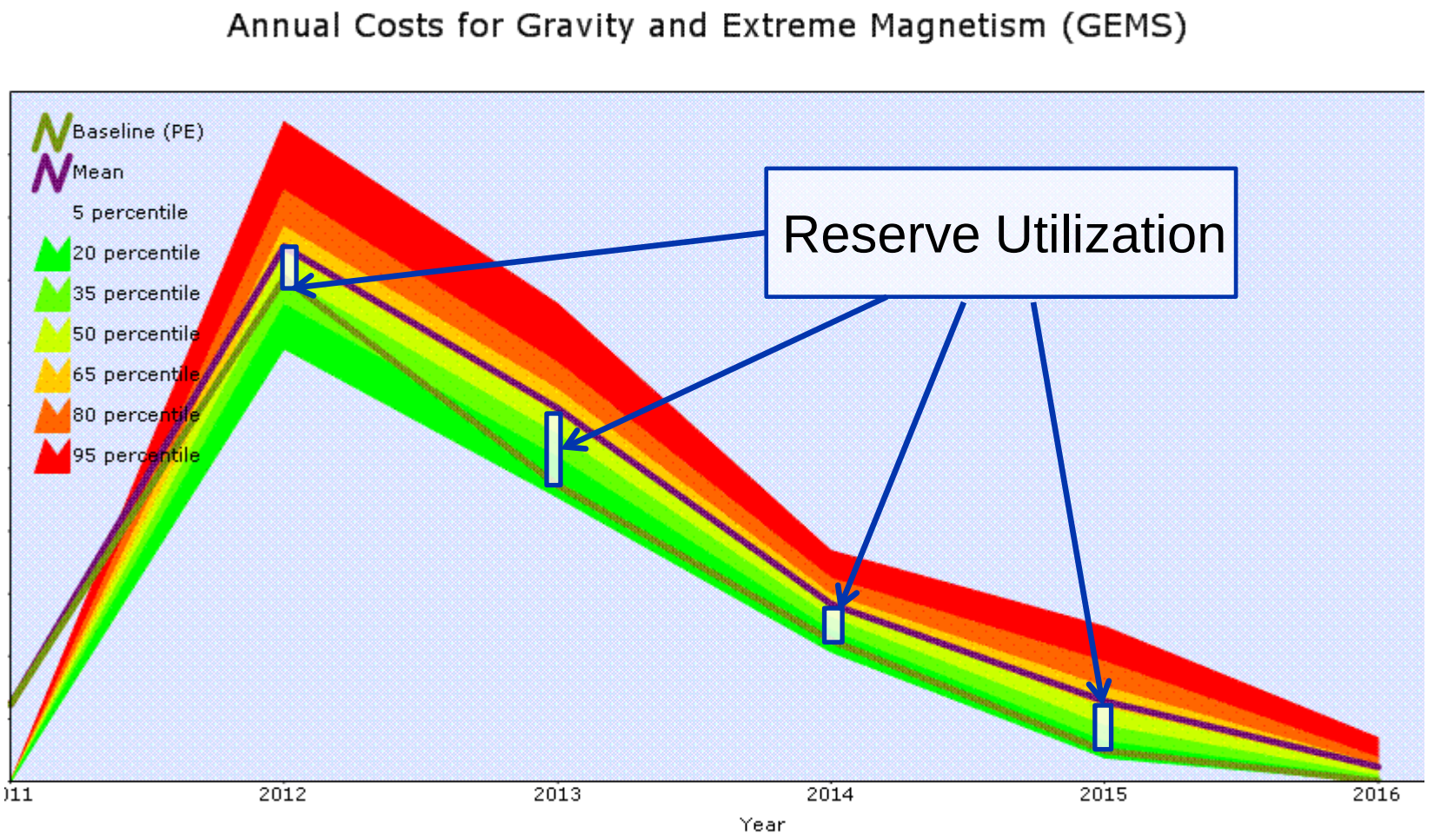


GEMS Milestone Progression Analysis



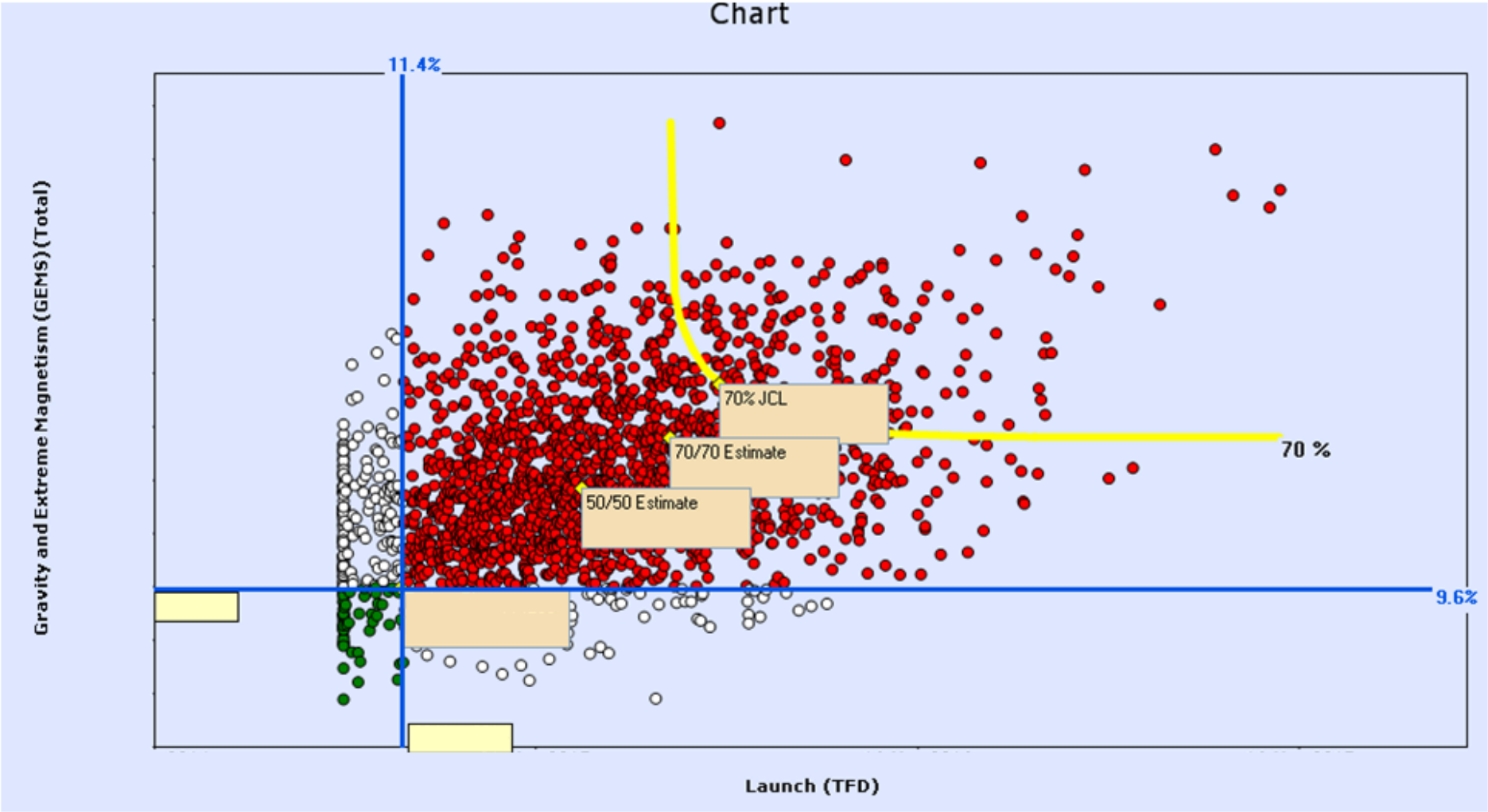
Annual Budget Captures Potential Costs Through LRD

Annual Cost Uncertainty Results



- Reserves identified by delta from plan to annual risk results.

Project Joint Confidence Level (JCL) Results



Notes:

- Budget without reserves of $$$M shown and Planned LRD of November 2014
-Scatter plot represents data points of a probabilistic estimate at complete with corresponding LRD

JCL Project Perspective

Project Lessons Learned

- What worked well:
  - Started the process early to support KDP-C requirement.
  - Dedicating time and availability to interact frequently with JCL modelers.
  - Open and honest exchange. The JCL modelers were provided access to project information and resources. They were updated on project status routinely.
  - Project team taking time to learn the JCL process and methodology.
  - Asking questions; the project did not just “data dump.”
  - Took a conservative approach:
    - Identified the real areas of uncertainty and risk.
    - Applied conservative uncertainty bands to increase final 50% and 70% confidence numbers from early draft models.

- What could have done better:
  - Underestimated the amount of time/energy from staff it took to help develop a JCL.
  - More involvement of technical leads from the subsystems.
  - Further education on what the JCL can show us to non-business staff is needed.
  - Modeled descope options: was an early thought, but time constraints limited us from pursuing.

The GEMS JCL was a valuable and valid model reflecting the project’s costs, risks, and schedule.

Policy Implementation Working Group

Policy Pause and Learn

- New policies at KDP-B and KDP-C institutionalized the creation of probabilistic estimates for cost and schedule, as well as JCL
  - What you just saw (the GEMS briefing package) is an output
- NASA has touted these actions in stakeholder discussions as key means to improve performance
  - Action to improve analysis, analysis to improve performance
- Casual examination suggests we still have challenges
  - **Questions on standard S curves and other outputs**
  - **GIGO is a concern, improving the inputs**
  - **Communication still problematic**
  - …

WG Background

- Policy Implementation Working Group formed in March 2012 at ECASG in response to community feedback
- Purpose includes improving the communication of analysis and results at KDP-B and KDP-C
- Provide overview of desirable features and template of outputs for presentation packages
- Jo put together her “Dream Package” using slides from the community
  - Presentation template for briefing results of KDP-B and KDP-C analysis
  - Actual presentation examples for positive reinforcement
  - Concise set of “key characteristics” that should be present in the briefings
- The GEMS briefing package contains many of the key characteristics Jo was developing with the WG

Desirable Features of Analysis Briefings for KDP-B and KDP-C

- **Provide a recap of the analysis with Key Findings**
  - Show the process and discuss the methodology (tell them what was done clearly)
- **Discussion of significant Groundrules and Assumptions**
  - Clearly identify any key GR&A's (e.g. scope limits, constraints, etc.)
- **Provide a simple and concise comparison to relevant analogies**
  - Provision of analogies/family with discussion of how the subject project relates
- **Show how Project metrics relate to analogies**
  - Display of relevant analogy/benchmarking data for both cost and schedule
- **Display Top Risks and compare to previous**
  - Identification of top risks (5x5) and any changes since design milestone (SDR, PDR), if two step process
- **Display of Risk Drivers/Tornado Chart from analysis results**
  - Identify and show, clearly, what contributes to risk in the model(s)
- **Discussion on development of uncertainty distributions**
  - Clearly identify how and WHY distributions are what they are (historical, SME, etc.)
- **Display of S-Curve results with annotations**
  - S-Curves should be clearly presented with annotations indicating value and confidence level
- **Display of key statistics, and justification for acceptability**
  - Show the relevant statistics from the model/analysis (e.g. mean, SD, CV, etc.)
- **If needed, discussion of how the Project position varies from SRB analysis**
  - Allow for SRB inclusion of additional risks, uncertainty, etc.

Some Fine Print

- Presentation packages vary by the audience type
  - Internal, to Local Mgmt, to Center, to SRB, to IPAO, to DPMC/APMC, etc.
  - What you just from GEMS was their brief to SRB/IPAO
- Estimators/Analysts do not always get 50 slides to brief their results to Sr. Management
  - Fortunate to be allocated more than 5
  - DPMC/APMC may show only an S-Curve or a Scatter Plot
  - How many of the original slides from GEMS made it to the DPMC?
- Jo certainly understood this, and endeavored to make her Dream Package comprehensive, so it could be distilled down as-needed
  - What stays/goes is a hot topic for discussion
  - Ultimately, by design, there is going to be a push to get more included and presented to Sr. Mgmt, need to find a balance

If we are going to make important decisions at KDP-B/C based on the analysis, we should be mindful of what is being presented

BACKUP