Blind Validation Study of PRICE TruePlanning and SEER-H

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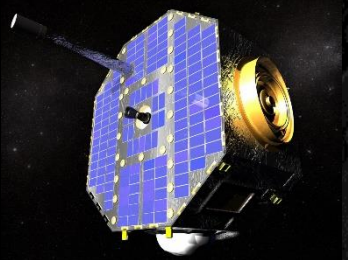
Motivation

- This work was originally presented at AIAA SPACE Conference in 2018 and published in Acta Astronautica in 2020
- Before this study no independent validation of PRICE and SEER was publicly available
- PRICE Systems and Galorath have performed validation studies of PRICE and SEER for NASA missions
  - PRICE is advertised to have an average error of +1% and standard deviation of 13%
  - SEER is advertised to have an average error of -1% and standard deviation of 19%
- The Goal of this Study is to independently assess the accuracy and precision of PRICE TruePlanning – Space Mission Catalog and SEER-H in a blind study

Methods

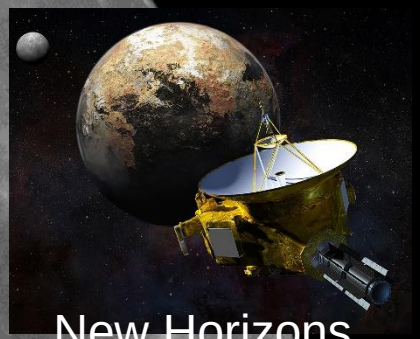
- 12 missions were selected from NASA's ONCE (One NASA Cost Engineering) database
- CADRes (Cost Analysis Data Requirements)
  - CADRes are summaries of technical and cost data for a science mission
  - Based on documents generated at major mission reviews
  - Often have important information missing such as the heritage of a particular component
- Supporting documents
  - Presentations/technical documents from CDR used to simulate estimation environment
- CADRes and supporting documents had all cost information removed before estimators had access to them
- Estimators were two aerospace engineering interns who were trained in the use of PRICE and SEER prior to beginning the study

Missions Selected


IBEX


CONTOUR


WISE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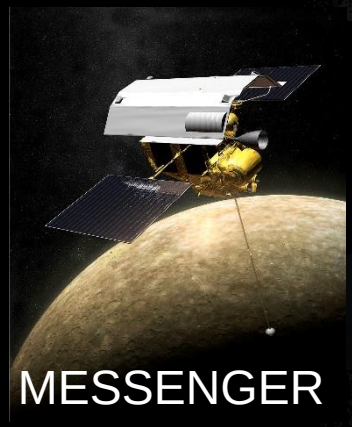
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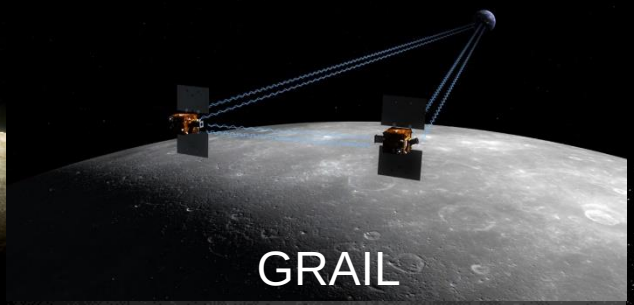
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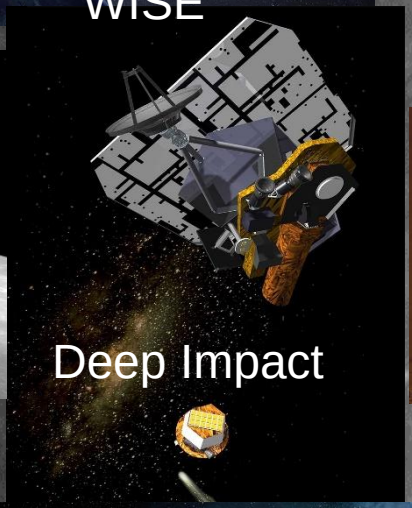
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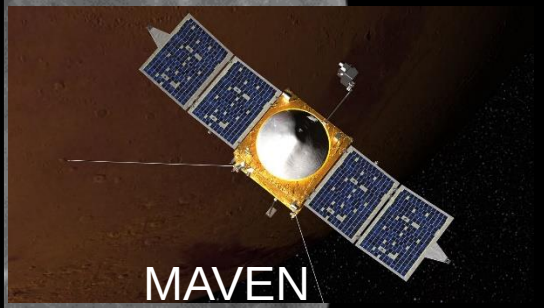
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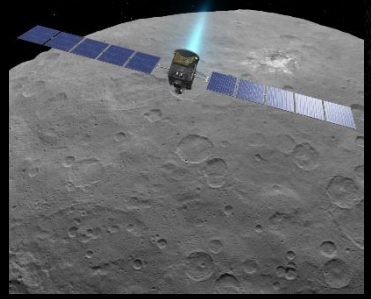
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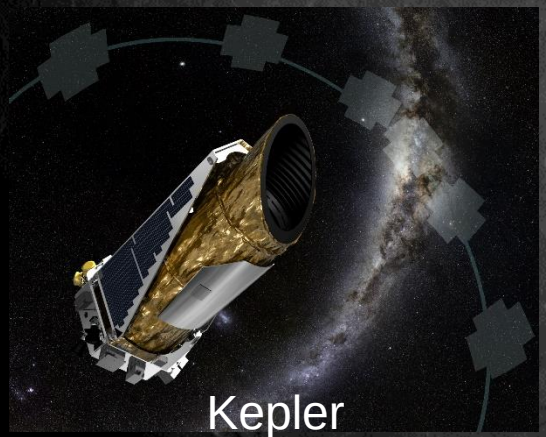
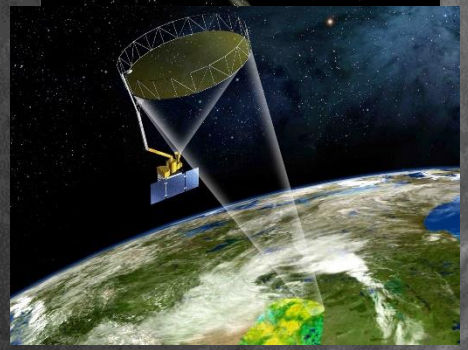

Kepler


SMAP


Juno

What costs are included in this study?

- PRICE and SEER estimated the WBS elements highlighted in *blue* below, i.e. WBS 1, 2, 3, 5, 6, 10
- NASA Work Breakdown Structure (WBS)
  - *1 Project Management*
  - *2 Systems Engineering*
  - *3 Safety & Mission Assurance*
  - 4 Science/Technology
  - *5 Payload*
  - *6 Spacecraft*
  - 7 Mission Operations
  - 8 Launch Vehicles/Services
  - 9 Ground Systems
  - *10 Systems Integration & Testing*
  - 11 Education and Public Outreach

Tool Comparison: Primary Cost Drivers

PRICE

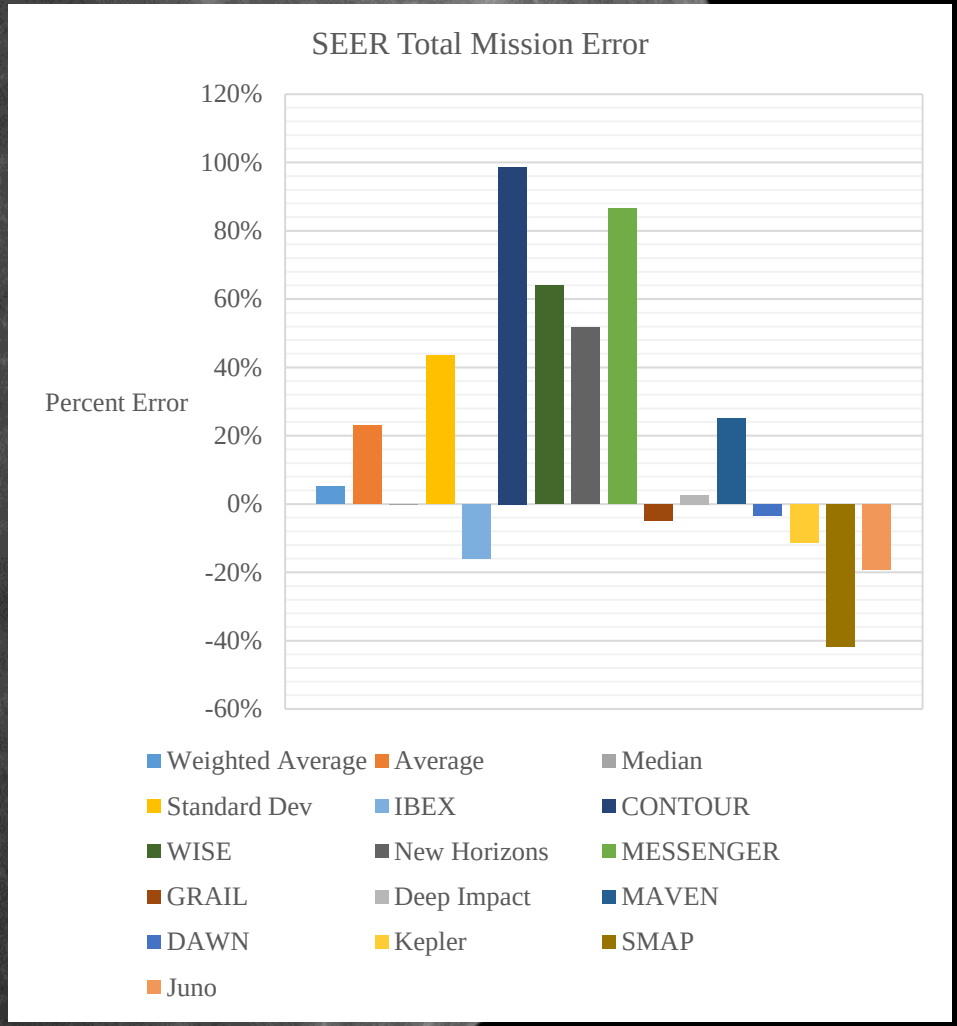
- Mass is primary scaling factor for all components
- All component types
  - Function
  - Heritage
  - Material
  - Complexity
  - Etc.
- “Calculators” can be used to guide input values

SEER

- Structures/Mechanisms
  - Mass, materials, complexity of fit/form, heritage
- Electronics
  - Number/function of boards, number of components/IO pins, clock speed, heritage, FPGAs/custom chips
- Optics
  - Element type, size, quantity, heritage
- Sensors
  - Sensor type, pixel size/quantity

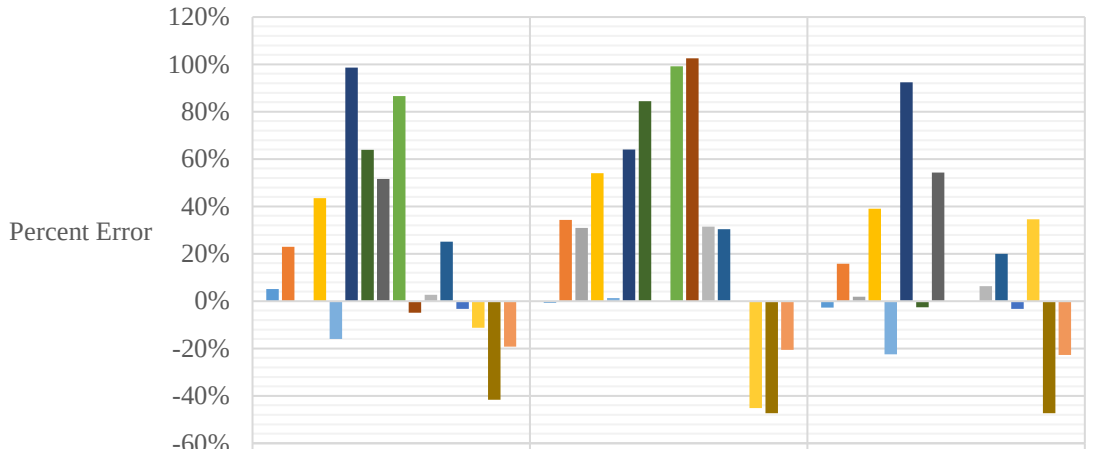
SEER's Error in Estimating Total Mission Costs

- Average error weighted by cost of missions: 5%
  - Meaning small systematic error
- Average error: 23%
- Median error: -0.3%
- Standard Deviation: 43%
- SEER is equally likely to overestimate or underestimate cost
- SEER tends to over estimate small missions and under estimate large missions



SEER Results – Payload and Spacecraft

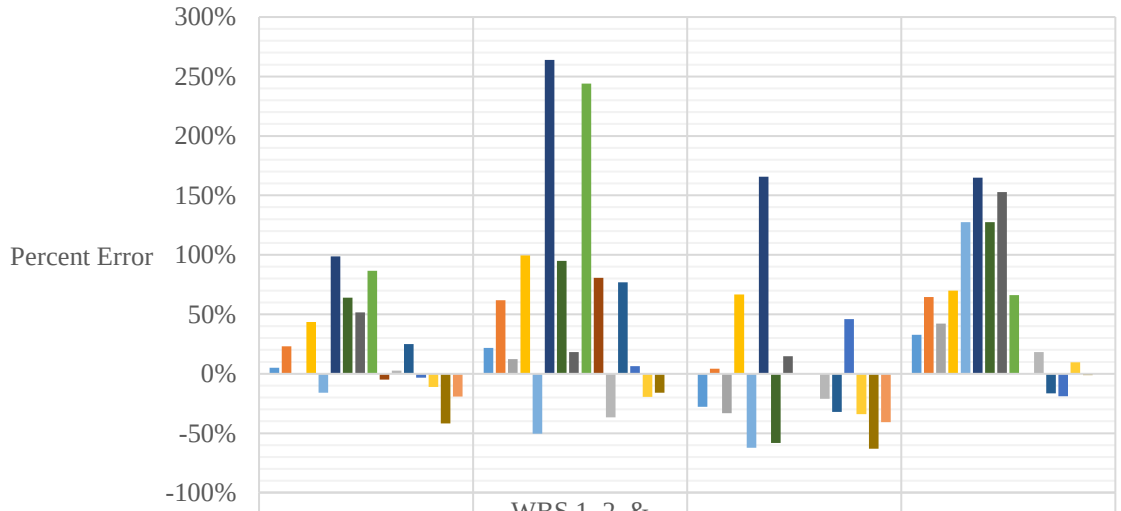
- Large variance in payload estimates likely due to lack of technical details provided in CADRe data
- WBS 5 Payload
  - Cost weighted average error-1%
  - Average error: 34%
  - Median error: 31%
  - Standard Deviation: 54%
- WBS 6 Spacecraft
  - Average error (weighted by cost): -3%
  - Average error: 16%
  - Median error: 2%
  - Standard Deviation: 39%



	Mission Total	WBS 5 - Payload Total	WBS 6 - Spacecraft Bus Total
Weighted Average	5%	-1%	-3%
Average	23%	34%	16%
Median	-0.3%	31%	2%
Standard Dev	43%	54%	39%
IBEX	-16%	1%	-22%
CONTOUR	99%	64%	92%
WISE	64%	84%	-3%
New Horizons	52%		54%
MESSENGER	87%	99%	
GRAIL	-5%	103%	
Deep Impact	3%	32%	6%
MAVEN	25%	30%	20%
DAWN	-3%		-3%
Kepler	-11%	-45%	35%
SMAP	-42%	-47%	-47%
Juno	-19%	-21%	-23%

SEER Results – System Level Costs

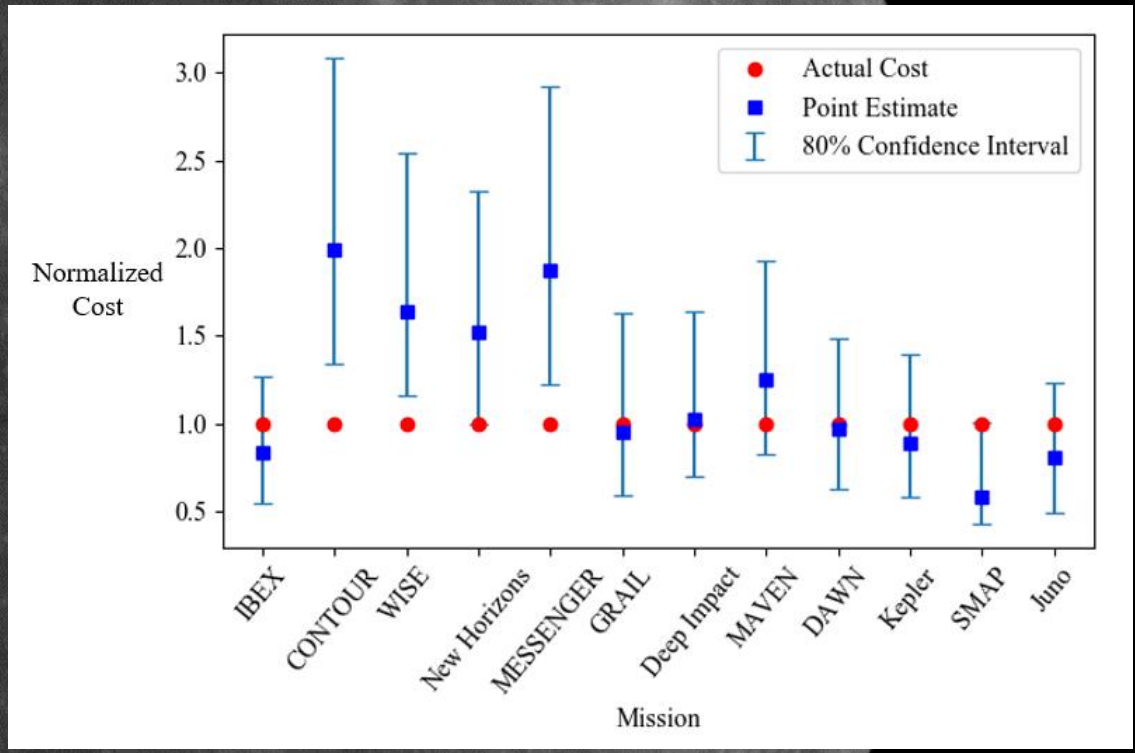
- SEER overestimates mission level systems costs
  - Cost weighted average error: 22%
  - Average error: 62%
  - Median error: 12%
  - Standard Deviation: 99%
- SEER underestimates spacecraft systems costs
  - Cost weighted average error: -28%
  - Average error: 4%
  - Median error: -33%
  - Standard Deviation: 67%
- WBS 10 IAT
  - Cost weighted average error: 33%
  - Average error: 64%
  - Median error: 42%
  - Standard Deviation: 70%
- Definitions:
  - PM (Project Management)
  - SE (Systems Engineering)
  - SMA (Safety and Mission Assurance)
  - IAT (Integration Assembly and Test)



	Mission Total	WBS 1, 2, & 3 - PM, SE, SMA	Spacecraft PM, SE, IAT	WBS 10 IAT
Weighted Average	5%	22%	-28%	33%
Average	23%	62%	4%	64%
Median	-0.3%	12%	-33%	42%
Standard Dev	43%	99%	67%	70%
IBEX	-16%	-50%	-62%	128%
CONTOUR	99%	264%	166%	165%
WISE	64%	95%	-58%	127%
New Horizons	52%	18%	15%	153%
MESSENGER	87%	244%		66%
GRAIL	-5%	81%		
Deep Impact	3%	-37%	-21%	18%
MAVEN	25%	77%	-32%	-16%
DAWN	-3%	6%	46%	-19%
Kepler	-11%	-19%	-34%	10%
SMAP	-42%	-16%	-63%	-1%
Juno	-19%	1%	-41%	

SEER Uncertainty Quantification

- User inputs optimistic, most likely, and pessimistic estimates for all inputs
  - Most of inputs are automatically filled by SEER
- 9 out of 12 (75%) of the missions fell in the 80% confidence interval
  - SEER's uncertainty capabilities performed as expected



Summary of SEER Results

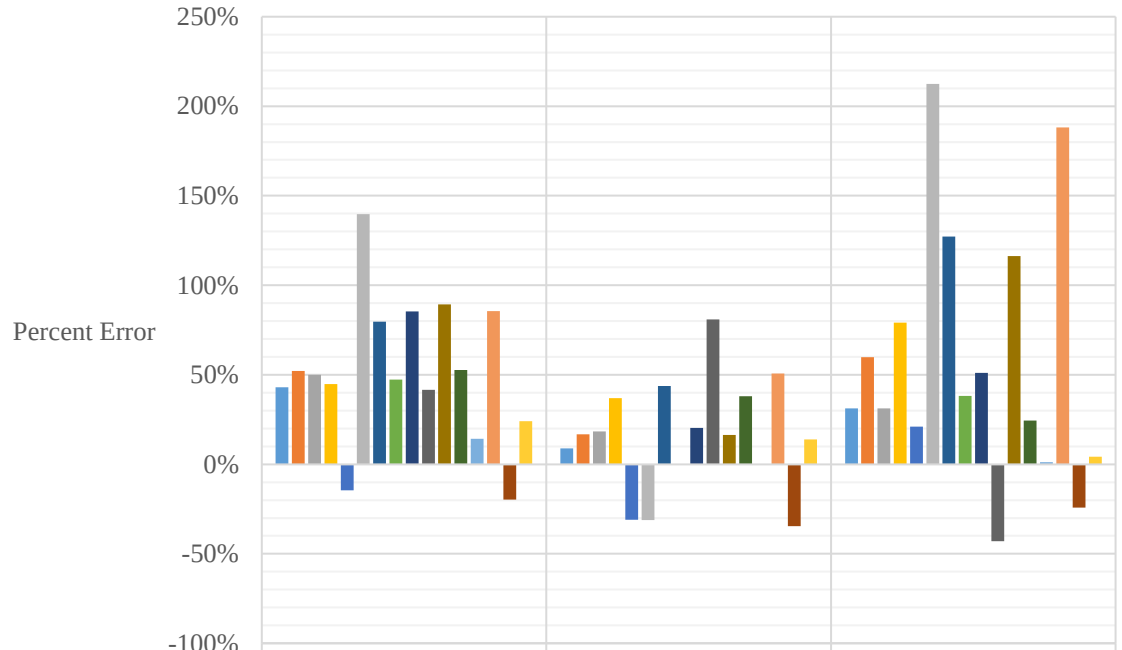
- Median error of -0.3%:
  - SEER just as likely to overestimate costs as underestimate them
- Average mission error of 23%:
  - When SEER overestimates the error is greater than when it underestimates
- Cost weighted average error: 5%
  - Meaning a low systematic error in the model as a whole
- Standard Deviation of 43%:
  - Point estimates have high variance
- SEER's uncertainty quantification capabilities performed as expected
  - 9 out of 12 (75%) of the missions fell in the 80% confidence interval

PRICE's Error in Estimating Total Mission Costs

- Average error (weighted by cost): 43%
- Average error: 52%
- Median error: 50%
- Standard Deviation: 45%
- All missions except for two were overestimated
- Large systematic error, but standard deviation not much larger than SEER
  - PRICE has similar precision to SEER

PRICE Results - Payload and Spacecraft

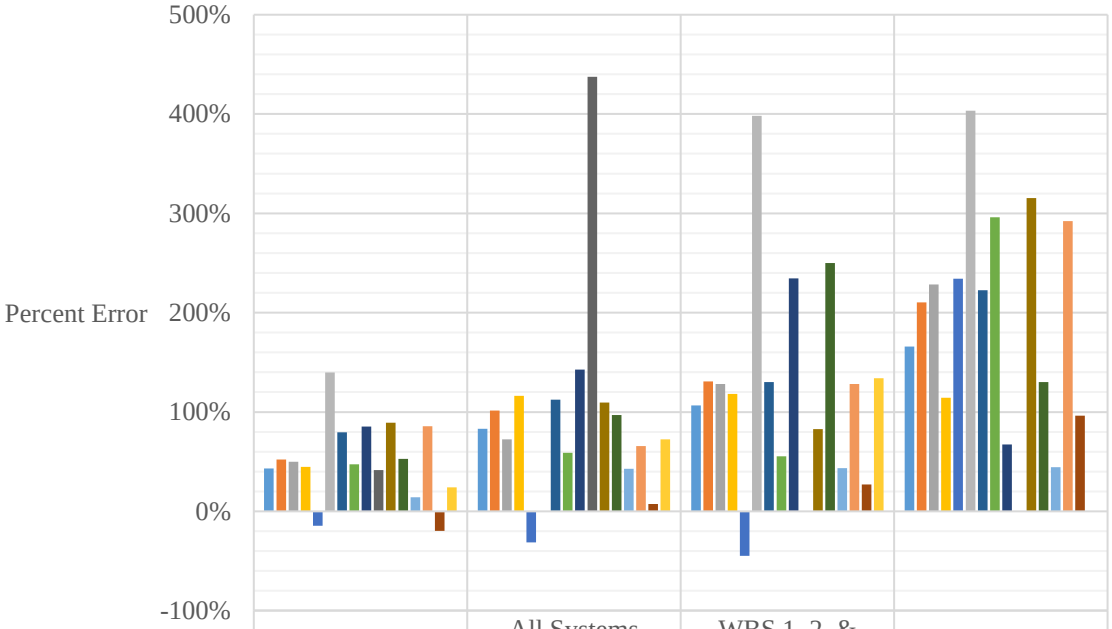
- PRICE's error and standard deviation for Payloads is much smaller than it is for spacecraft
- WBS 5 Payload
  - Average error (weighted by cost): 9%
  - Average error: 17%
  - Median error: 18%
  - Standard Deviation: 37%
- WBS 6 Spacecraft
  - Average error (weighted by cost): 31%
  - Average error: 60%
  - Median error: 31%
  - Standard Deviation: 79%



	Mission Total	Payload Subsystems Total	Spacecraft Bus Subsystem Total
Weighted Average	43%	9%	31%
Average	52%	17%	60%
Median	50%	18%	31%
Standard Dev	45%	37%	79%
IBEX	-15%	-31%	21%
CONTOUR	140%	-31%	213%
WISE	80%	44%	127%
New Horizons	47%		38%
MESSENGER	85%	20%	51%
GRAIL	42%	81%	-43%
Deep Impact	89%	16%	116%
MAVEN	53%	38%	24%
DAWN	14%		1%
Kepler	86%	51%	188%
SMAP	-20%	-35%	-24%
Juno	24%	14%	4%

PRICE Results – System Level Costs

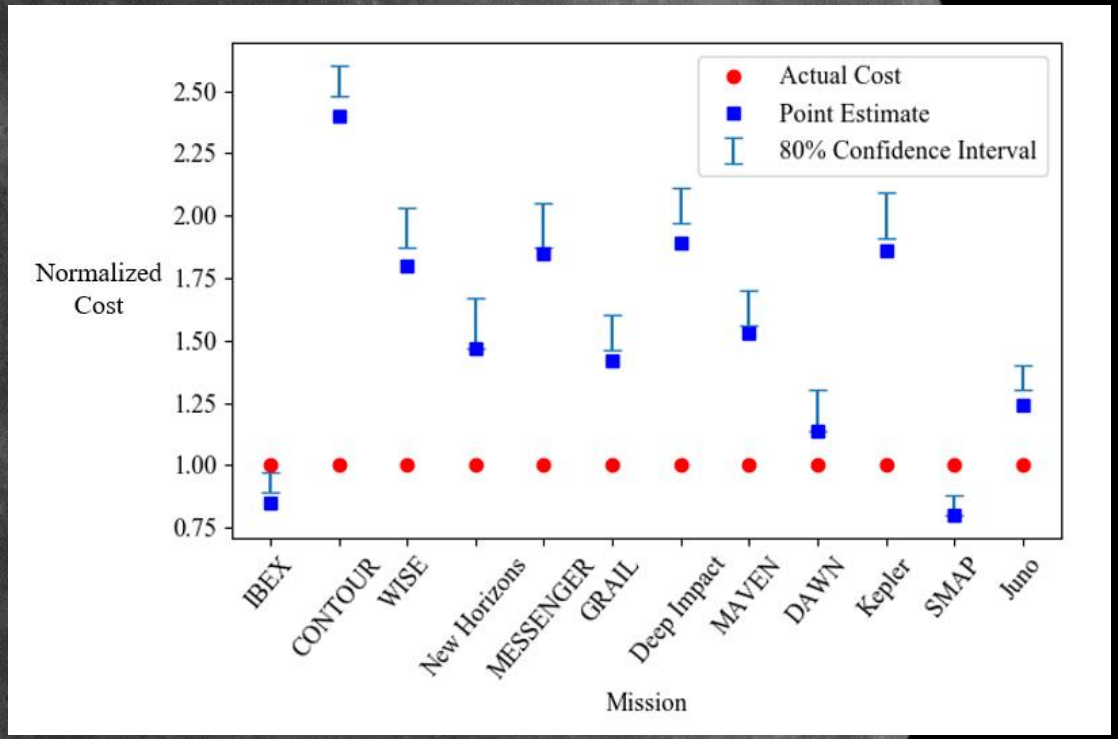
- Extremely large errors in predicting system level costs
- WBS 1, 2, & 3:
  - Average error (weighted by cost): 106%
  - Average error: 131%
  - Median error: 128%
  - Standard Deviation: 118%
- WBS 10 IAT:
  - Average error (weighted by cost): 166%
  - Average error: 210%
  - Median error: 228%
  - Standard Deviation: 114%
- System level errors are likely driven by subsystem level errors.



	Mission Total	All Systems Costs (WBS 1, 2, 3, & 10)	WBS 1 ,2, & 3 - PM, SE, SMA	WBS 10 IAT
Weighted Average	43%	83%	106%	166%
Average	52%	101%	131%	210%
Median	50%	72%	128%	228%
Standard Dev	45%	116%	118%	114%
IBEX	-15%	-31%	-45%	234%
CONTOUR	140%		398%	403%
WISE	80%	113%	130%	223%
New Horizons	47%	59%	56%	296%
MESSENGER	85%	143%	235%	67%
GRAIL	42%	437%		
Deep Impact	89%	110%	83%	315%
MAVEN	53%	97%	250%	130%
DAWN	14%	43%	43%	44%
Kepler	86%	66%	128%	292%
SMAP	-20%	7%	27%	96%
Juno	24%	72%	134%	

PRICE Uncertainty Quantification

- User inputs optimistic, most likely, and pessimistic estimates for some inputs
  - No uncertainty inputs are auto filled in PRICE
- None of the missions fell in the 80% confidence interval
- Point estimates typically fell at the 0-10% confidence level, i.e. outside the 80% confidence interval



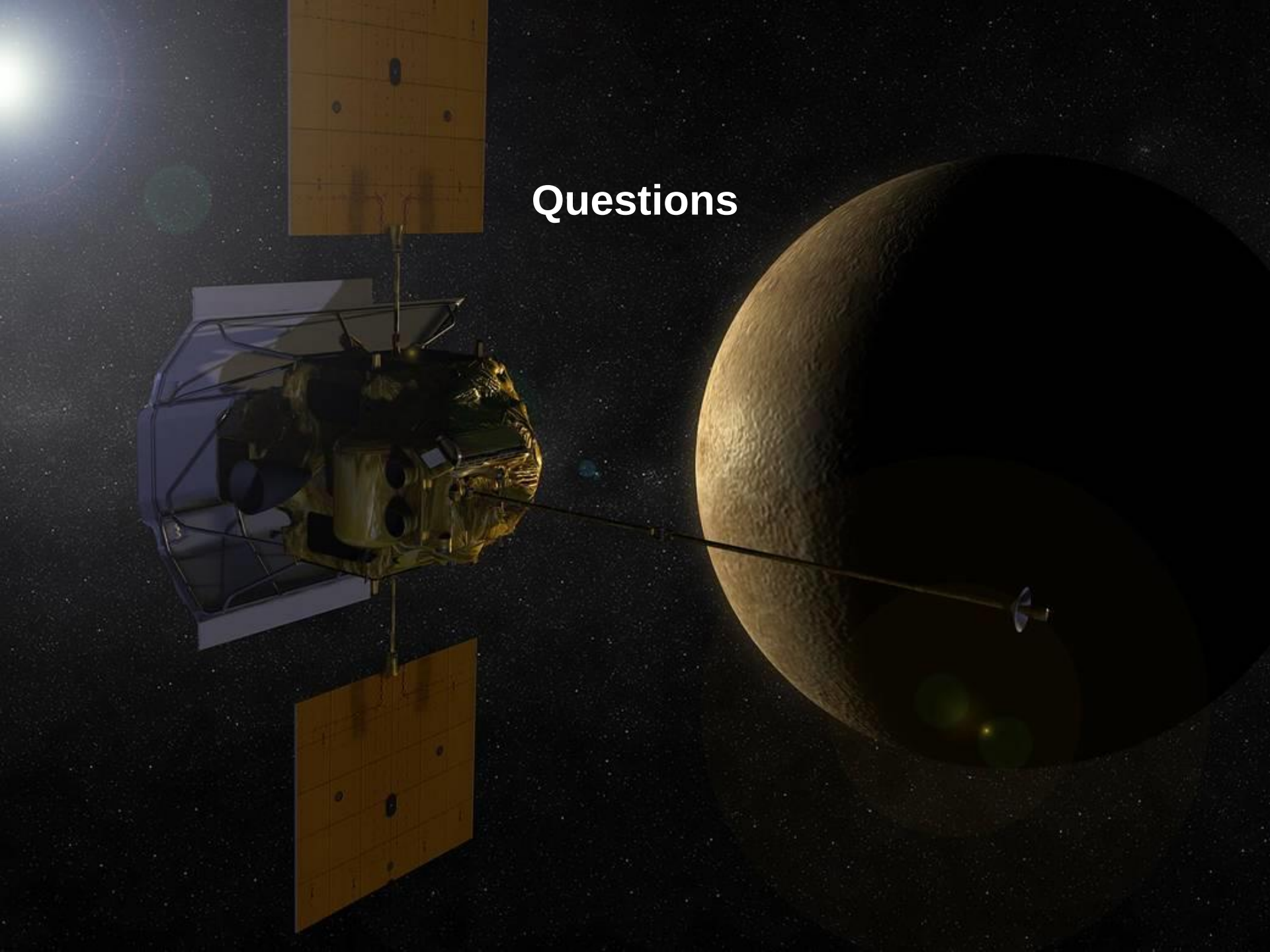
Discussion

- Mass Estimating
  - Common Assumptions
    - Optimistic: Current best estimate
    - Most Likely: Current best estimate + contingency
    - Pessimistic: Most Likely + 30%
  - Mass estimates from CDR (Critical Design Review) were used
    - 30% estimate was likely excessive and drove up the SEER estimate
- Using CDR rather than launch data added excess uncertainty
- Prototyping Assumptions
  - Standard assumption of 1.3 prototypes for components without documented number of prototypes
- Subject Matter Experts/Missing Documentation
  - Missions in this study took place over the past 20 years
  - It was not possible to ask clarifying questions about the hardware
  - This results in large uncertainty in inputs to PRICE and SEER
- Experience of Estimators
  - Estimators had formal training from PRICE Systems LLC in the use of PRICE
  - Estimators had informal training in SEER and completed several training exercises prior to beginning the study
  - Estimators had access to experienced estimators for questions

Conclusions

- SEER's uncertainty quantification capabilities performed as expected
  - 9 out of 12 (75%) of the missions fell in the 80% confidence interval

- Both SEER and PRICE had large errors and standard deviations
  - External factors which may have affected the results include:
    - Mass margin assumptions
    - Conflating uncertainty in design with uncertainty in the models
    - Prototyping assumptions
    - Inability to ask clarifying questions to subject matter experts
    - Experience of the estimators


Questions

Backup

Contact information

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  - Paul.D.Friz@nasa.gov
  - 757.864.2050

Outline

- Motivation
- Methods
- Tool Comparison (PRICE vs. SEER)
- SEER Results
- PRICE Results
- Discussion
- Conclusions

Introduction

- What is parametric costing?
  - Using a set of cost estimating relationships to predict cost when only a few key pieces of data are known
  - Cost estimating relationships are derived from historical data.
- Parametric costing tools are…
  - Commonly used at NASA and in industry to estimate life cycle costs of future space missions
  - Allow users to quickly estimate the cost of a mission concept before detailed designs have been completed
  - Frequently used by NASA to evaluate spacecraft and instrument proposals
- Two parametric costing tools commonly used at NASA are…
  - PRICE TruePlanning (Space Mission Catalog) by PRICE Systems LLC
  - SEER-H (with EOS and IC plugins) by Galorath Inc

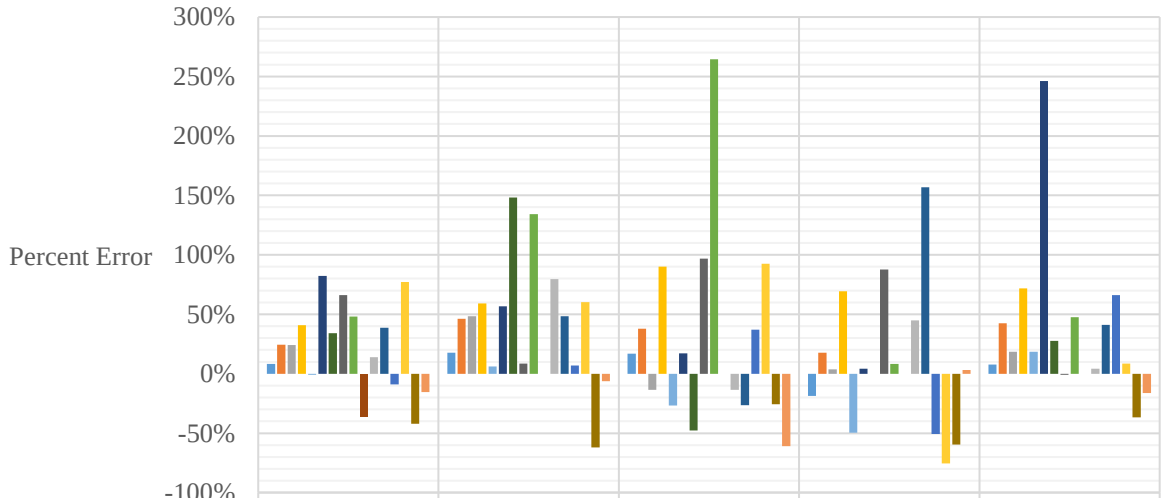
What Do PRICE and SEER Estimate?

- PRICE and SEER were used to estimate the following items.
- NASA Work Breakdown Structure (WBS)
  - 1 Project Management
  - 2 Systems Engineering
  - 3 Safety & Mission Assurance
  - 4 Science/Technology
  - 5 Payload
  - 6 Spacecraft
  - 7 Mission Operations
  - 8 Launch Vehicles/Services
  - 9 Ground Systems
  - 10 Systems Integration & Testing
  - 11 Education and Public Outreach

- WBS 6: Spacecraft, is broken down further
  - Project Management
  - Systems Engineering
  - Integration, Assembly, and Test
  - Structures
  - Thermal
  - Propulsion
  - Guidance, Navigation, and Control (GN&C)
  - Communication
  - Electrical Power
  - Harness
  - Command and Data Handling (C&DH)

SEER Results – Spacecraft Subsystems

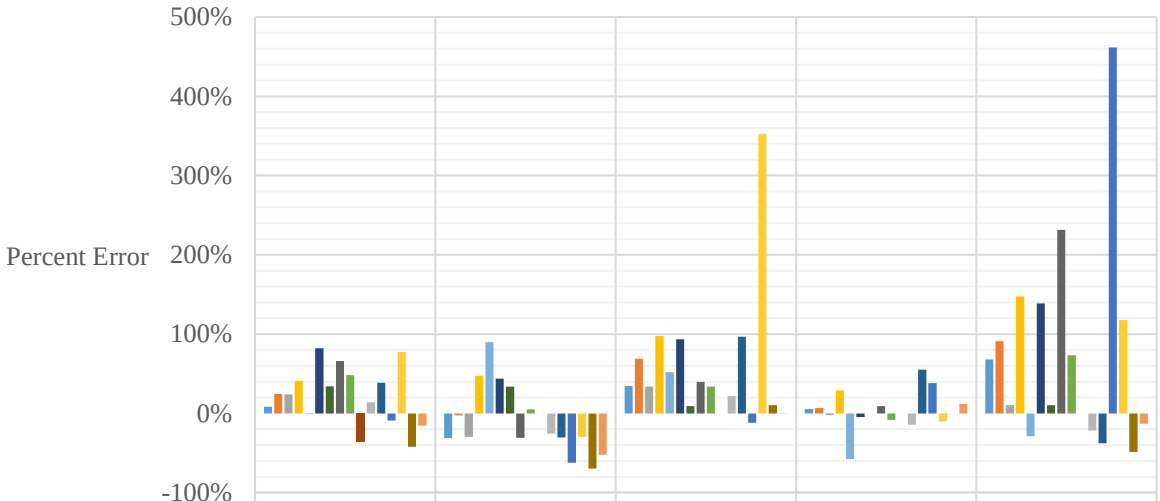
- Large errors in estimating individual subsystems tend to average each other out.



	Bus Subsystems Total	Structures	Thermal	Propulsion	GN&C
Weighted Average	8%	18%	17%	-19%	8%
Average	24%	46%	38%	18%	43%
Median	24%	48%	-14%	4%	19%
Standard Dev	41%	59%	90%	69%	72%
IBEX	-1%	6%	-27%	-50%	19%
CONTOUR	82%	57%	17%	4%	246%
WISE	34%	148%	-48%		28%
New Horizons	66%	8%	97%	88%	-1%
MESSENGER	48%	134%	264%	8%	48%
GRAIL	-36%				
Deep Impact	14%	80%	-14%	45%	4%
MAVEN	39%	48%	-27%	157%	41%
DAWN	-9%	7%	37%	-51%	66%
Kepler	77%	60%	93%	-75%	9%
SMAP	-42%	-62%	-26%	-60%	-37%
Juno	-15%	-6%	-61%	3%	-16%

SEER Results – Spacecraft Subsystems

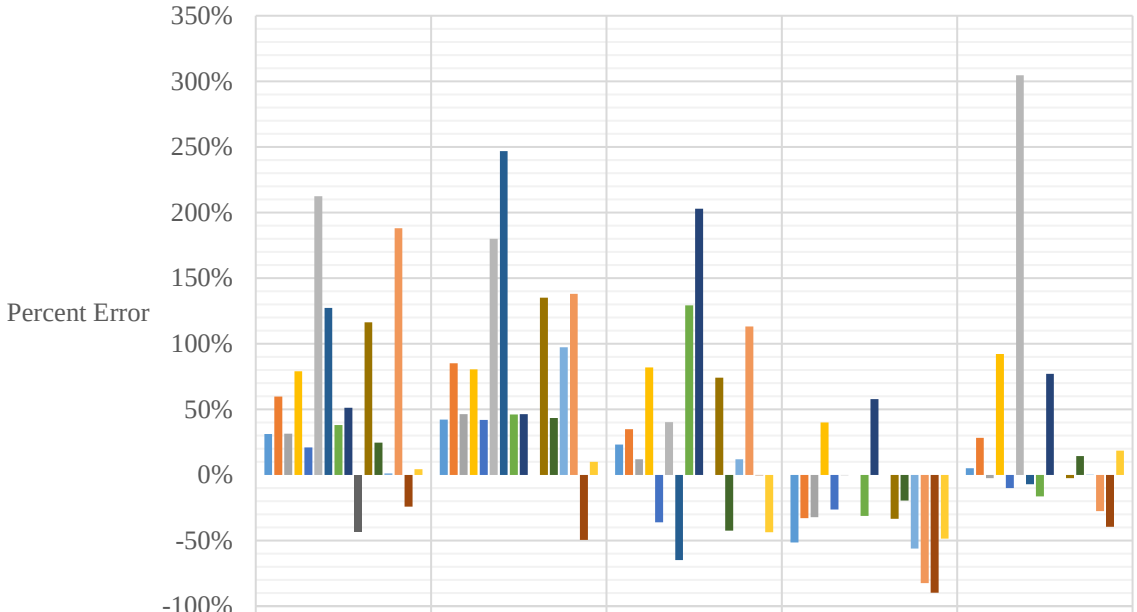
- Extremely large errors in C&DH and Power subsystems due to lack of knowledge of heritage.



	Bus Subsystems Total	Comm	Electrical Power	Harness	C&DH
Weighted Average	8%	-31%	35%	6%	68%
Average	24%	-2%	69%	7%	91%
Median	24%	-30%	34%	-2%	10%
Standard Dev	41%	47%	97%	29%	148%
IBEX	-1%	90%	52%	-57%	-29%
CONTOUR	82%	44%	93%	-5%	139%
WISE	34%	34%	9%		10%
New Horizons	66%	-31%	40%	9%	232%
MESSENGER	48%	5%	34%	-8%	73%
GRAIL	-36%				
Deep Impact	14%	-26%	21%	-14%	-22%
MAVEN	39%	-30%	97%	55%	-38%
DAWN	-9%	-62%	-12%	38%	462%
Kepler	77%	-30%	352%	-10%	118%
SMAP	-42%	-70%	10%	0%	-48%
Juno	-15%	-52%	0%	12%	-13%

PRICE Results – Spacecraft Subsystems

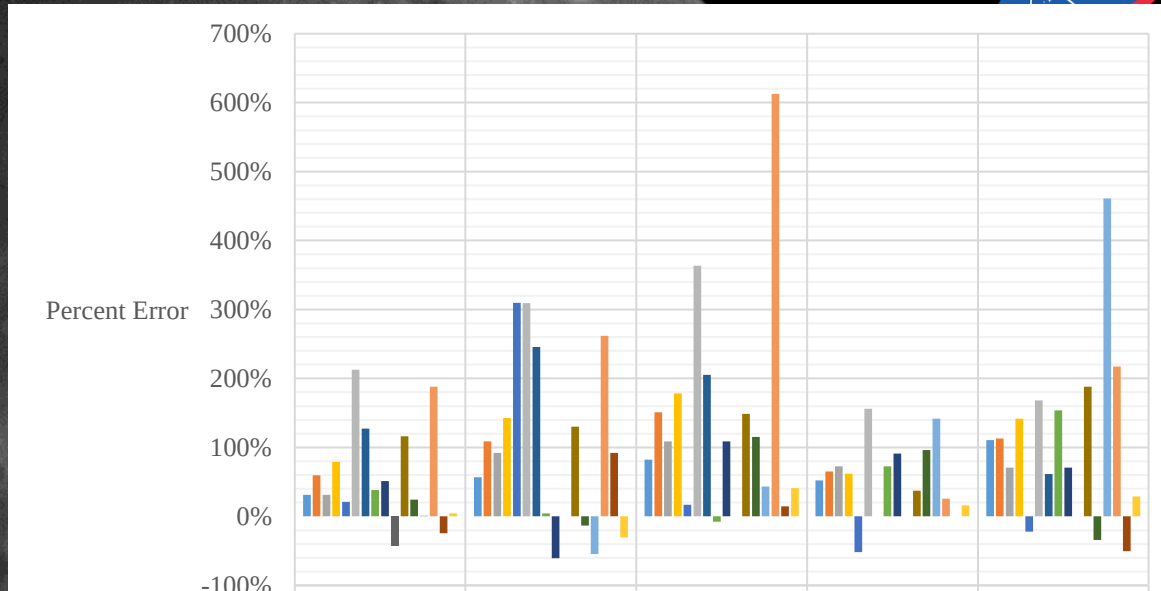
- Large errors in predicting costs of individual subsystems.



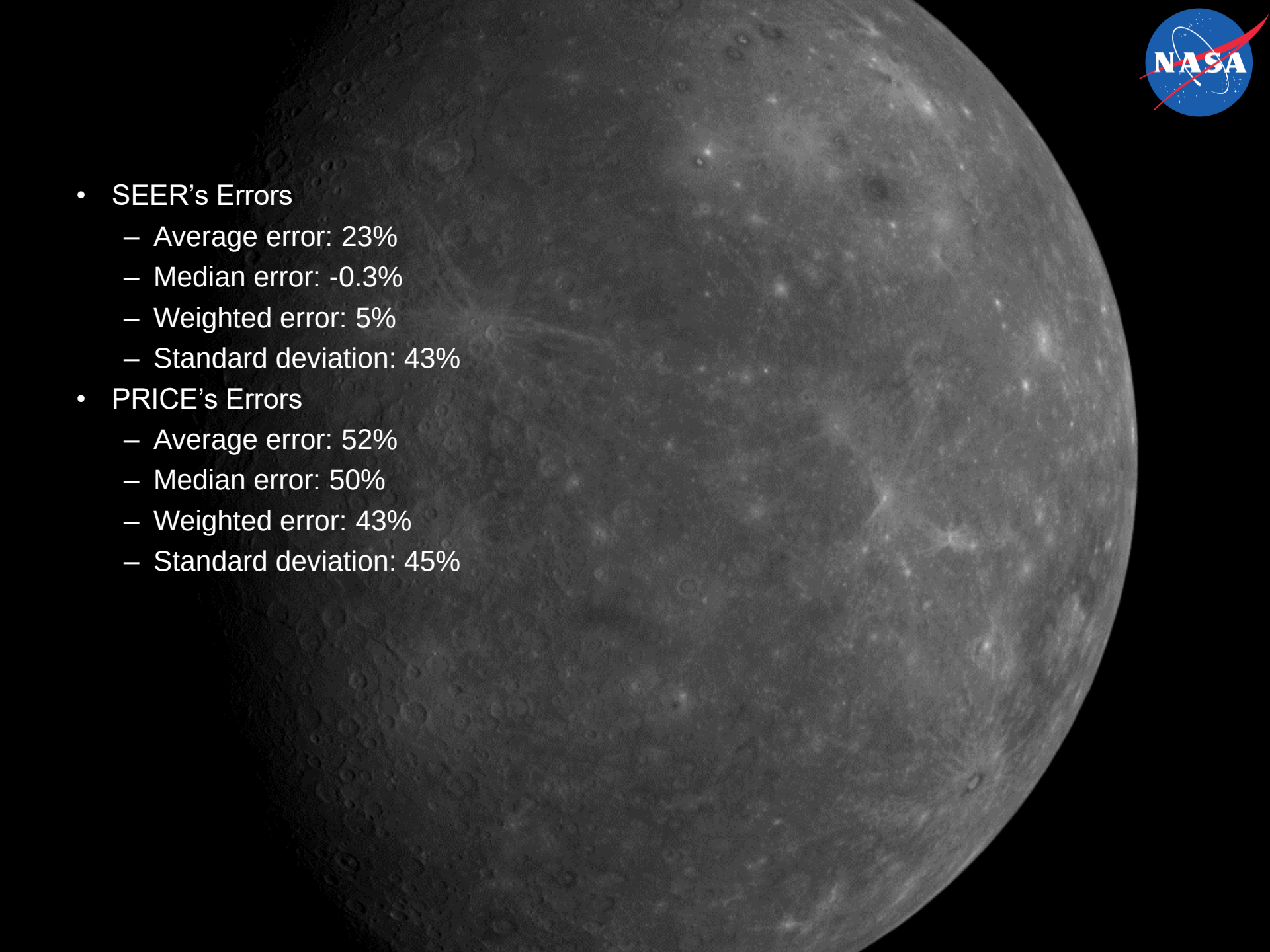
	Spacecraft Bus Subsystem Total	Structures	Thermal	Propulsion	GN&C
Weighted Average	31%	42%	23%	-51%	5%
Average	60%	85%	35%	-33%	28%
Median	31%	46%	12%	-32%	-2%
Standard Dev	79%	80%	82%	40%	92%
IBEX	21%	42%	-36%	-26%	-10%
CONTOUR	213%	180%	40%	-0.2%	305%
WISE	127%	247%	-65%		-7%
New Horizons	38%	46%	129%	-31%	-16%
MESSENGER	51%	46%	203%	58%	77%
GRAIL	-43%				
Deep Impact	116%	135%	74%	-34%	-2%
MAVEN	24%	43%	-43%	-20%	14%
DAWN	1%	97%	12%	-56%	0.1%
Kepler	188%	138%	113%	-82%	-28%
SMAP	-24%	-50%	-0.1%	-90%	-40%
Juno	4%	10%	-44%	-49%	19%

PRICE Results – Spacecraft Subsystems

- Largest standard deviations are in subsystems which are primarily electronics.
  - C&DH
  - Power
  - Communications
  - GN&C



	Spacecraft Bus Subsystem Total	Comm	Electrical Power	Harness	C&DH
Weighted Average	31%	57%	82%	52%	111%
Average	60%	109%	151%	65%	113%
Median	31%	92%	109%	73%	71%
Standard Dev	79%	143%	178%	62%	142%
IBEX	21%	310%	17%	-52%	-22%
CONTOUR	213%	309%	363%	156%	168%
WISE	127%	245%	205%		62%
New Horizons	38%	4%	-8%	73%	154%
MESSENGER	51%	-61%	109%	91%	71%
GRAIL	-43%				
Deep Impact	116%	130%	149%	37%	188%
MAVEN	24%	-13%	115%	96%	-34%
DAWN	1%	-55%	43%	142%	461%
Kepler	188%	262%	613%	26%	217%
SMAP	-24%	92%	15%		-51%
Juno	4%	-31%	41%	16%	29%



- SEER’s Errors
  - Average error: 23%
  - Median error: -0.3%
  - Weighted error: 5%
  - Standard deviation: 43%
- PRICE’s Errors
  - Average error: 52%
  - Median error: 50%
  - Weighted error: 43%
  - Standard deviation: 45%