The Space Between Us: A Novel Collaborative Spacecraft Estimating Framework

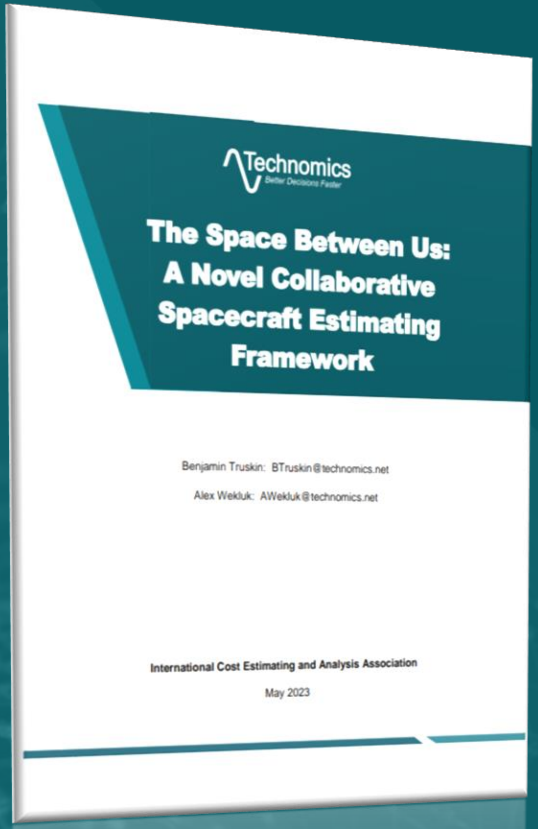
Technomics
Better Decisions Faster

ICEAA Professional Development Workshop

May 2023

Agenda

Check out our Long-Form Research Paper!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The Space Between Us: A Novel Collaborative Spacecraft Estimating Framework

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International Cost Estimating and Analysis Association

May 2023

- Introduction & The Space Community
- Parametrics & Today's Environment
- SPACEFRAME: Behind the Curtain
- A Realistic Case Study
- Takeaways & Best Practices
- Next Steps

The Team

Benjamin Truskin

Project Manager

A project manager and employee owner at Technomics with 10 years experience providing data-driven decisions to leaders. He has provided support to groups within the IC, DoD, and Civilian space. Ben's experience includes: cost estimation and phasing, data policy and normalization, methods development, source selection support, industry interface, database requirements development. He received his Master's and Bachelor's in Aerospace Engineering from The Pennsylvania State University.

Alex Wekluk

Associate Program Manager

Alex Wekluk is an ICEAA Certified Cost Estimator/Analyst (CCEA) and Employee Owner at Technomics. He has eighteen years of experience performing cost, risk, and technical analyses for the DoD and the IC. He secured a USPTO patent for weapon design work and earned the IC Meritorious Unit Citation for exemplary cost-reduction analysis. He holds a BS in Mechanical Engineering from Virginia Tech and a MA in Economics from George Mason University. He is co-author on another ICEAA 2023 paper: "Shining Rays of Light & Savings on Cloud Portfolios."

Space, It's Big

- As an industry, space is big and rapidly growing, both nationally and internationally
  - Growth spans commercial, civil, military, intelligence functions
  - As business models and technology mature, government is looking for beneficial partnerships

- Projected to grow from $469B in 2021 to >$1T by 2040

OneWeb
ACCESS FOR EVERYONE

IMMEDIATE RELEASE

Department of Defense Establishes U.S. Space Force

DEC. 20, 2019

Project Kuiper announces plans and launch provider for prototype satellites

November 1, 2021

DIRECTV

STARLINK

iridium

SDA
SPACE DEVELOPMENT AGENCY

SPACENEWS

JWST gets mid-December launch date

by Jeff Foust — September 9, 2021

NASA

ARTEMIS

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Space Cost Community Challenges

There is a significant opportunity for greater comparability and increased collaboration leading to improved methods and models across the community

NRO CAAG
- CTDR
- DSCM
- CER Library

NASA
- CADRE
- PCEC
- NICM

USSF SSC
- Flexfiles
- USCM

ODNI CAAG
- AoA Model
- Box-level Cost Model
- Method Dev Template

LIMITED SHARING AND CROSS-AGENCY APPLICABILITY

A common framework allows agencies to readily compare models and methods!

Method Comparability Challenges

Application

- Not all Recurring CERs are equal
  - T1 vs. AUC vs. Total REC
- $/month vs. Total $
- What types of acquisitions apply?

Variable Definitions

- Heritage (e.g. %New Design, TRL, 0.01-10 'Heritage Scale', mod categories)
- Mass (pounds?, kilograms?, stones?!)
- What is meant by 'Total Cost'? What program phases? What burdens and taxes?

Functional Forms

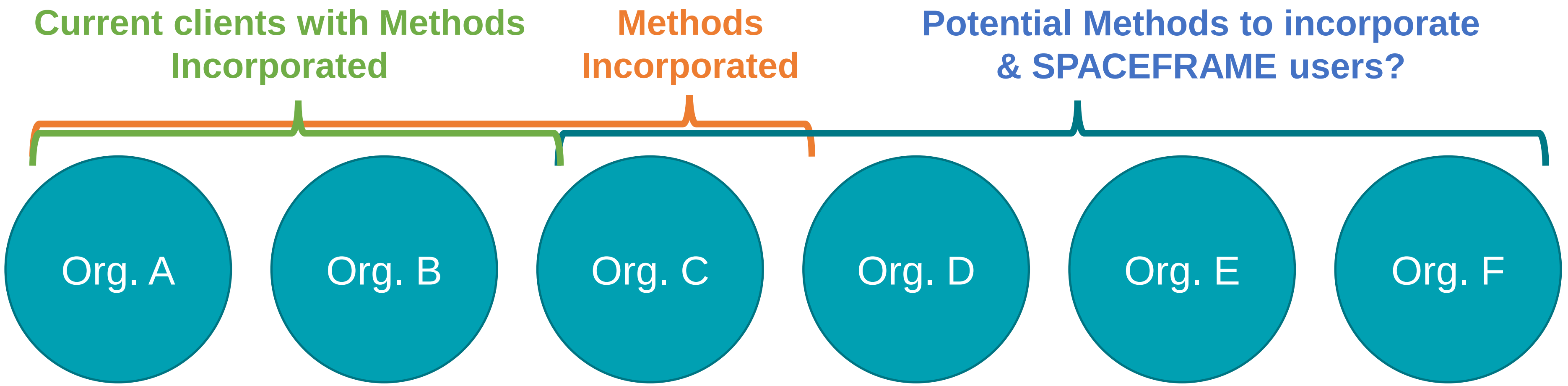
- $\$ = a * Mass^b * c^{Stratifier}$ vs. $\$ = a * Mass^b * Stratifier^c$
  - A small-looking change with big impacts
- 2 term linear CER vs. 6 term non-linear piecewise CER

SEITPM

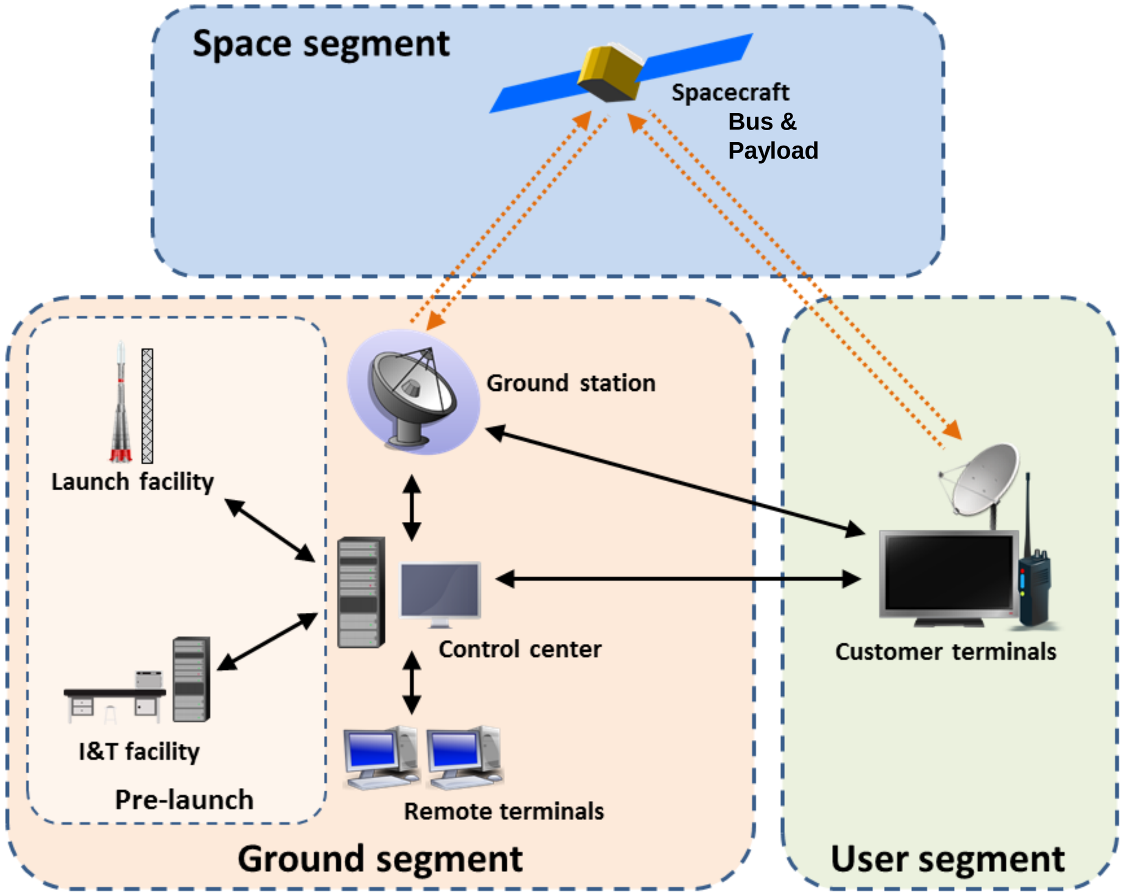
- Groups don't ascribe integration activities to the same levels!
  - How you normalize affects how methods are developed
- Reliance on underlying estimates (aka base)
- Sub-models as inputs to methods
  - Is the sub-model released?!

Welcome to SPACEFRAME

- Space Parametric Cost Estimating Framework (SPACEFRAME) is a framework of parametric cost models tailored to space systems
  - Incorporates existing, released methods
  - Modular methods to be incorporated into an Excel-based methods library
  - Allows for additional method inclusion as well as updated existing methods as they are released to the broader community – focus on space systems, could potentially apply to various other commodities
- A collection of methods from a variety of organizations, spanning levels of space system WBS



Space System Estimating Introduction



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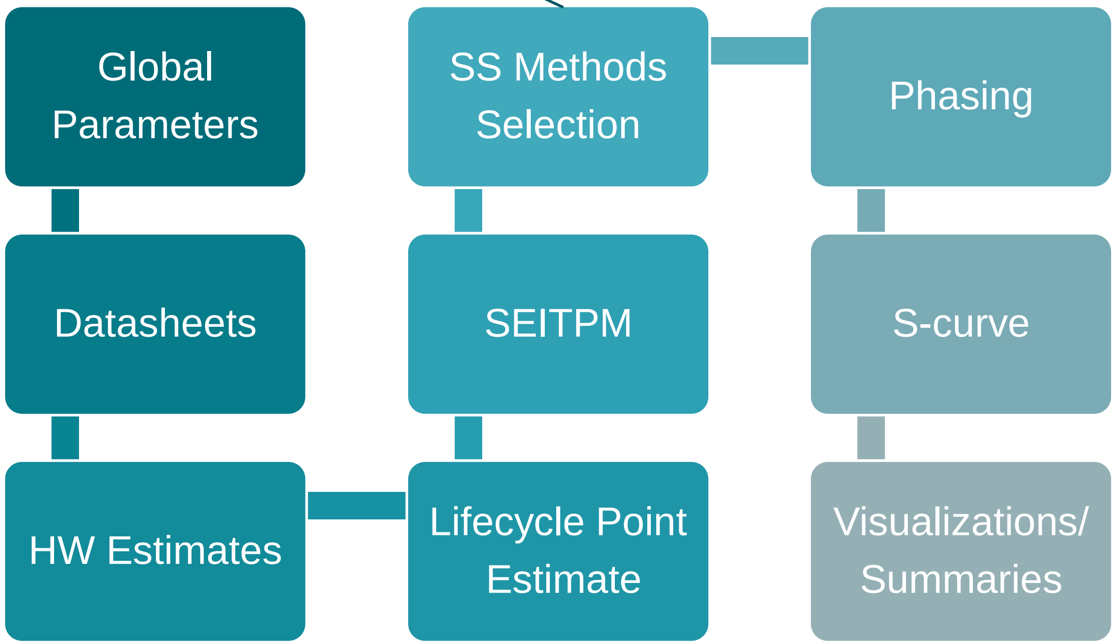
Focus of SPACEFRAME and Case Studies

Ability to incorporate, not focus of SPACEFRAME

SPACEFRAME Architecture

Each box represents an Excel sheet in SPACEFRAME performing a specific set of functions in the estimating process



Features

- ✓ Excel-based
- ✓ Modular
- ✓ Traceable
- ✓ Customer IT-network compatible
- ✓ Adaptable to client estimating processes

Technical Inputs

Globals

- Estimating inputs needed throughout
  - Inflation
  - Estimate Base/Common Year
  - Schedule
- Scope (e.g., Launch, Ground, Operations)
- Client specific inputs are easy to add and document. Examples we've used include:
  - FOREX factors
  - Mission Assurance adjustments
  - Simplified Risk Factors

Technical Baseline

- Standardized Datasheets inform space estimating methods
  - Mass
  - Quantities
  - Heritage
- May also include other technical measures (depending on methods selected
  - E.g., Optics size, Transmission Power, Solar Array Area, Structure Material Type

A Common Methods Library (Simplified Example)

- The backbone enabling SPACEFRAME automation!
  - Significant effort was expended to standardize, enabling the automatic calculation

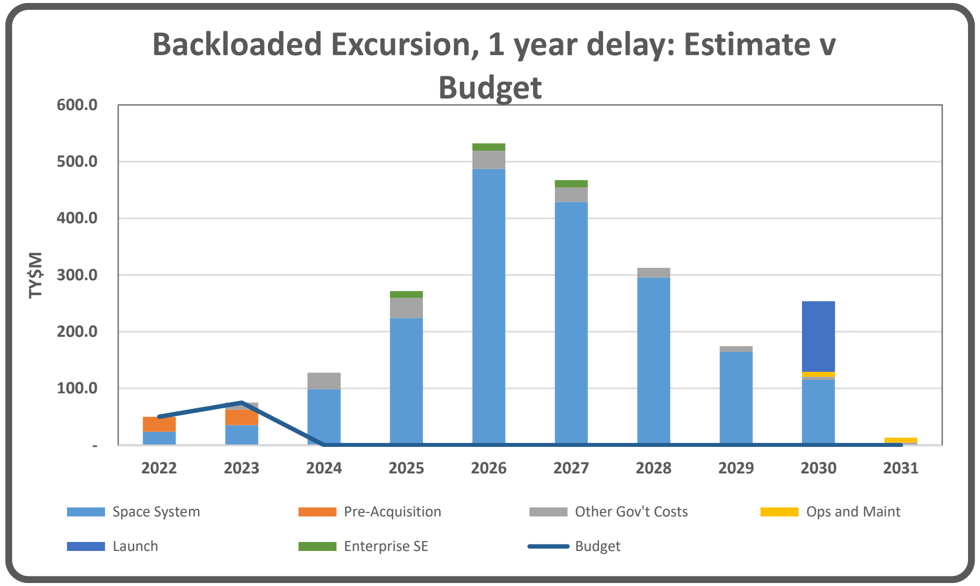
REC Subsystem CERs

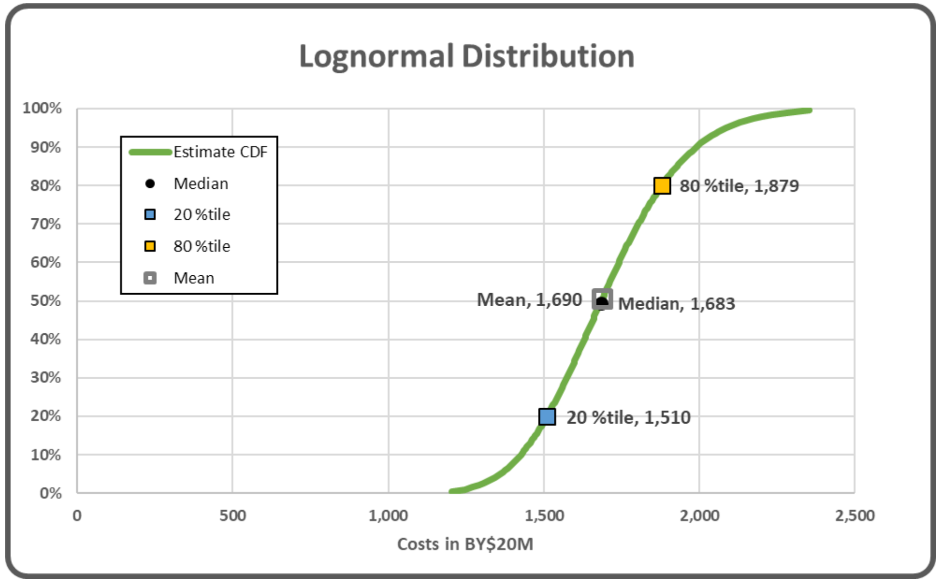
CER	Ind Var 1	Ind Var 2	Ind Var 3	Ind Var 4	Ind Var 5	Ind Var 6	BY	Adj	NR Pair	Dep Var	Form
Org A_REC_Widget X	Maximum Power (W)	New Tech? (1/0)					2000	1	Org A_NR_Widget X	AUC (BY00$k)	100*Mass (lb)^0.5*BPC^-0.2*Maximum Power (W)^0.3*1.2^New Tech?
Org B_REC_Widget X	Gimbaled? (e/1)						2000	1	Org B_NR_Widget X	T1 (BY00$k)	150*Mass (lb)^0.7*BPC^-0.3*Gimbaled?^0.2
⋮							⋮	⋮	⋮	⋮	⋮
Org D_REC_Widget Z	Data Rate (Mbps)	Multi-channel? (1/0)					2020	1	Org D_NR_Widget Z	AUC (BY20$k)	80*Mass (lb)^0.9*BPC^-0.1*Data Rate (Mbps)^(0.01-0.1*Multi-channel?)

- Technomics has curated 225+ disparate methods into a common structure
  - Spans 6 major categories of CERs, as well as other types of estimating relationships

Standardized Outputs

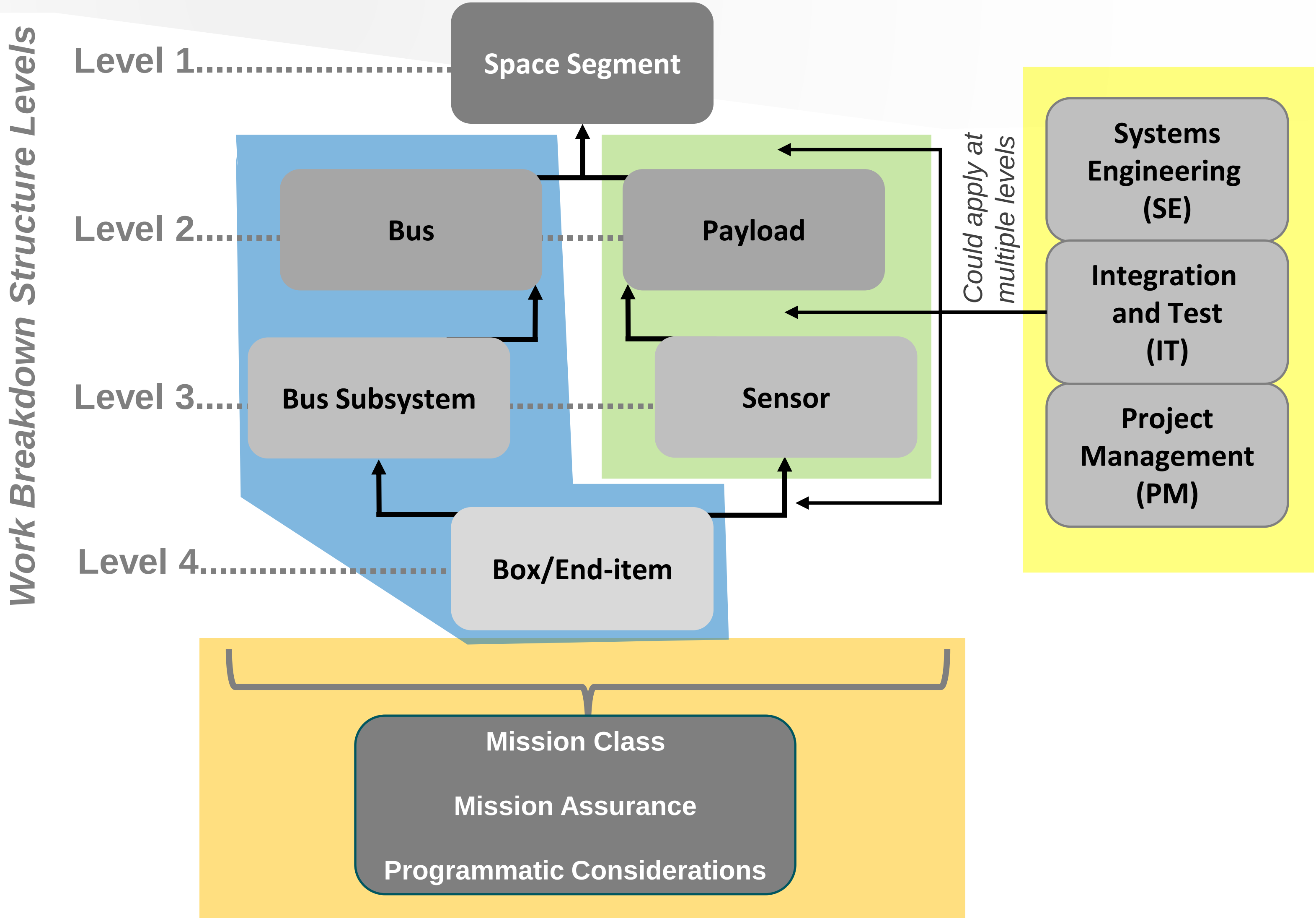
Element	2024	2025	2026	2027	2028	Prior	FYDP	Future	Total
Total (TY$M)	370.6	445.8	417.1	316.2	214.3	101.5	1,764.1	432.9	2,298.4
Space System	329.7	398.6	371.9	290.8	197.0	35.5	1,588.0	230.4	1,853.9
Pre-Acquisition	-	-	-	-	-	53.4	-	-	53.4
Other Gov't Costs	28.9	34.9	32.6	25.5	17.3	12.5	139.0	20.2	171.7
Ops and Maint	-	-	-	-	-	-	-	60.8	60.8
Launch	-	-	-	-	-	-	-	121.5	121.5
Enterprise SE	12.1	12.3	12.6	-	-	-	37.1	-	37.1





Case Study Context

- Unfortunately, organizations don't spend millions or more to build space systems just to satisfy the curiosity of cost analysts!
- Our case study will focus on a fictional 'simple' spacecraft
  - Communications System, single unit
- Case Study is representative of an acquisition any space organization may undertake



Case Study 1

Case Study 2

Case Study 3

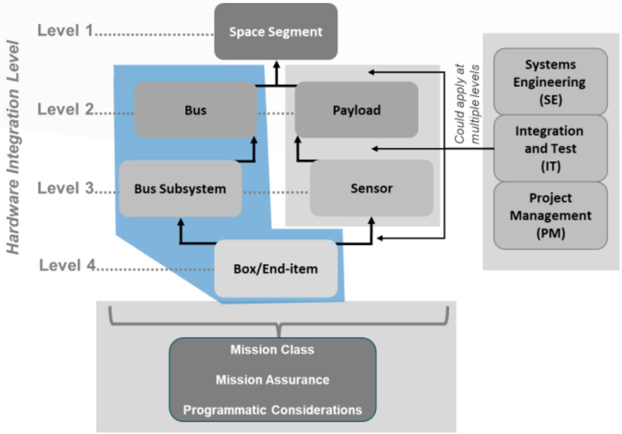
Case Study 4

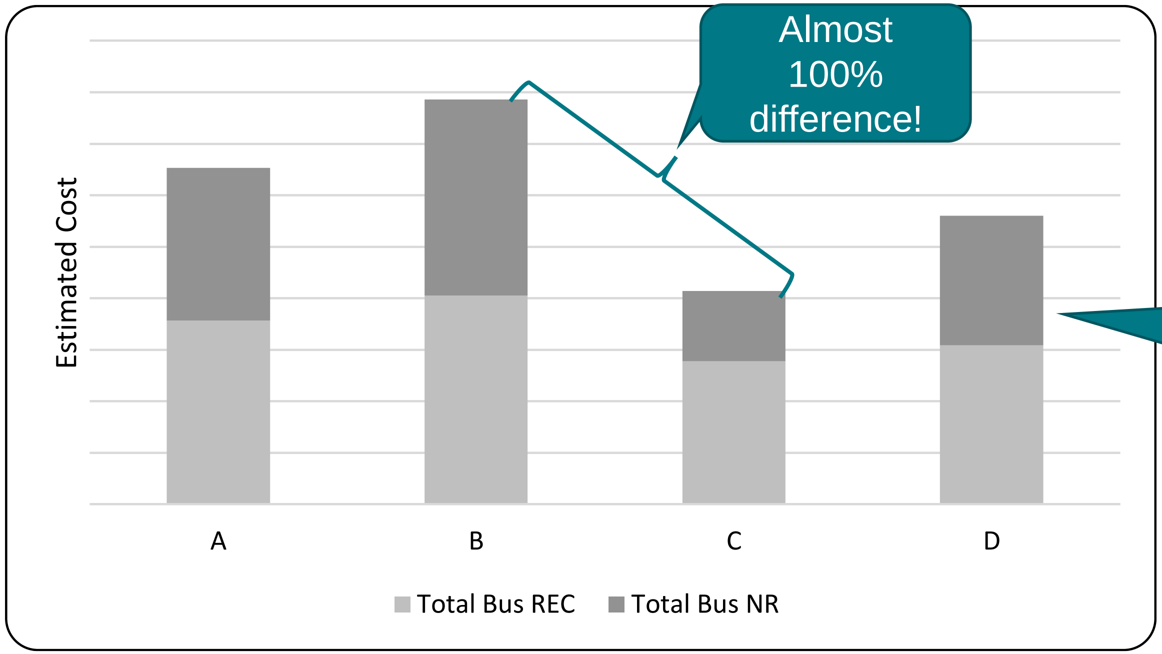
Case Study 1: Bus Boxes & Subsystems

Bus
ACS Subsystem
Star Tracker
Inertial Reference Unit
Control Moment Gyros
Attitude Control Electronics
EPS Subsystem
Solar Array Wing
Li-Ion Batteries
Power Converter (Bus to PL)
EPS Cables & Harnesses
PRS Subsystem
Fuel Tank
Thruster A
Propulsion Interface Unit
SMS&TCS Subsystem
Primary Structures
Secondary Structures
Heat Pipes & Radiators
MLI Blankets
TT&C Subsystem
GPS Antenna (Helix)
Narrowband (NB) Patch Antenna
NB Receiver
Command Relay Unit

Snippet of WBS

- For Case Study 1, team estimated bus subsystem costs: positioning (ACS), power (EPS), propulsion (PRS), structures / thermal (SMS/TCS), and commanding (TT&C) at box-level
- Boxes include solar arrays, batteries, star trackers, electronics, thrusters, GPS antennas and command receivers
- Discovered significant difference in estimates, especially in NR

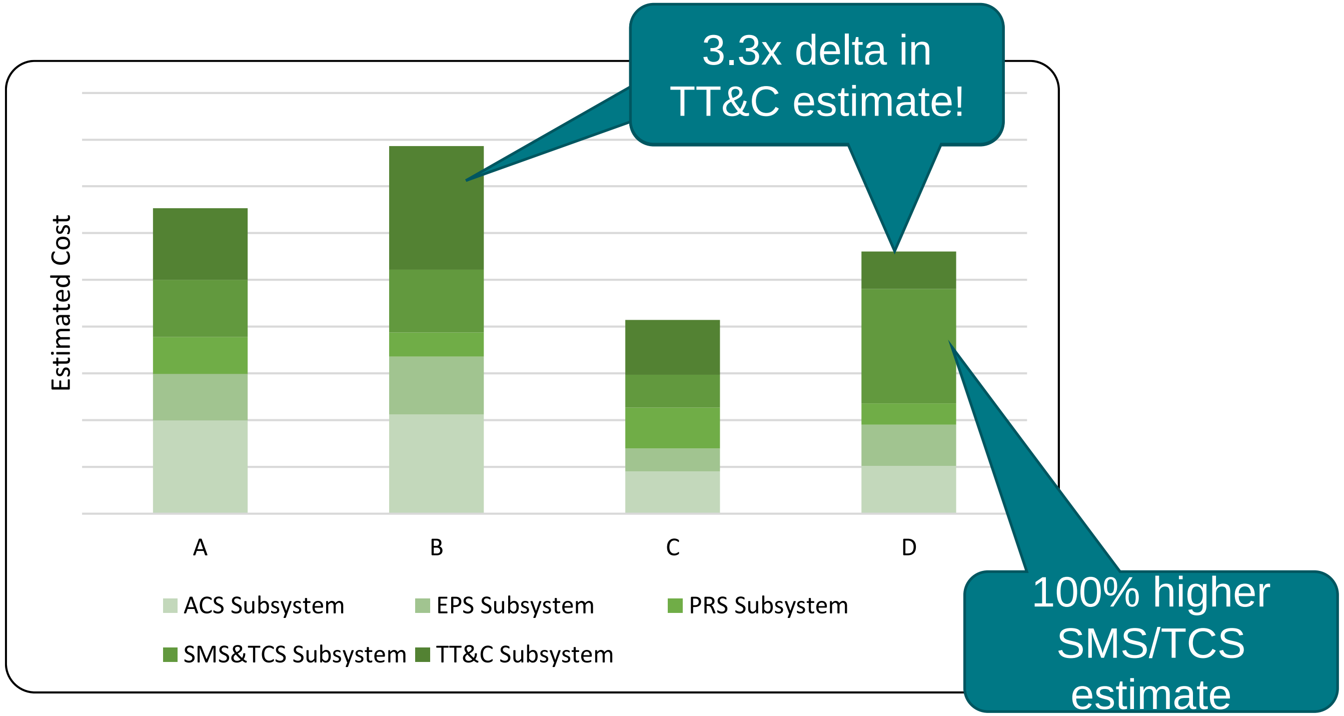


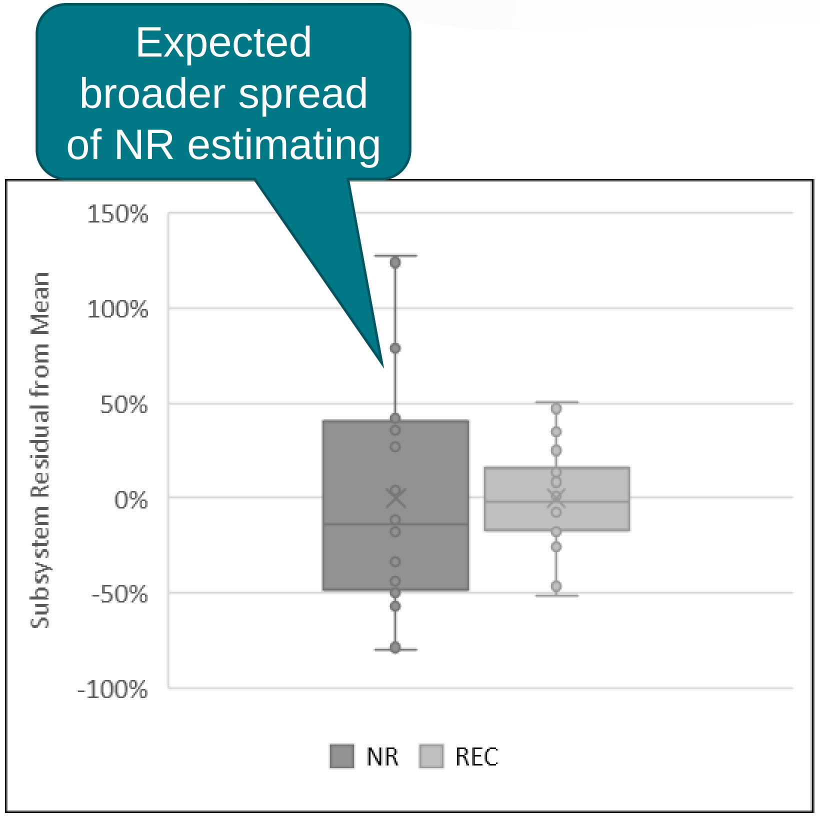


NR methods show significantly more spread, upwards of 150% difference

Case Study 1: Bus Boxes & Subsystems

- Discovered large differences in allocation of costs between subsystems, and in spread around NR estimates vs R estimates

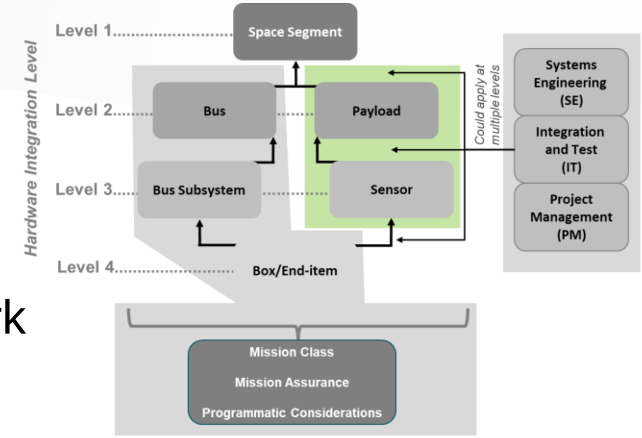


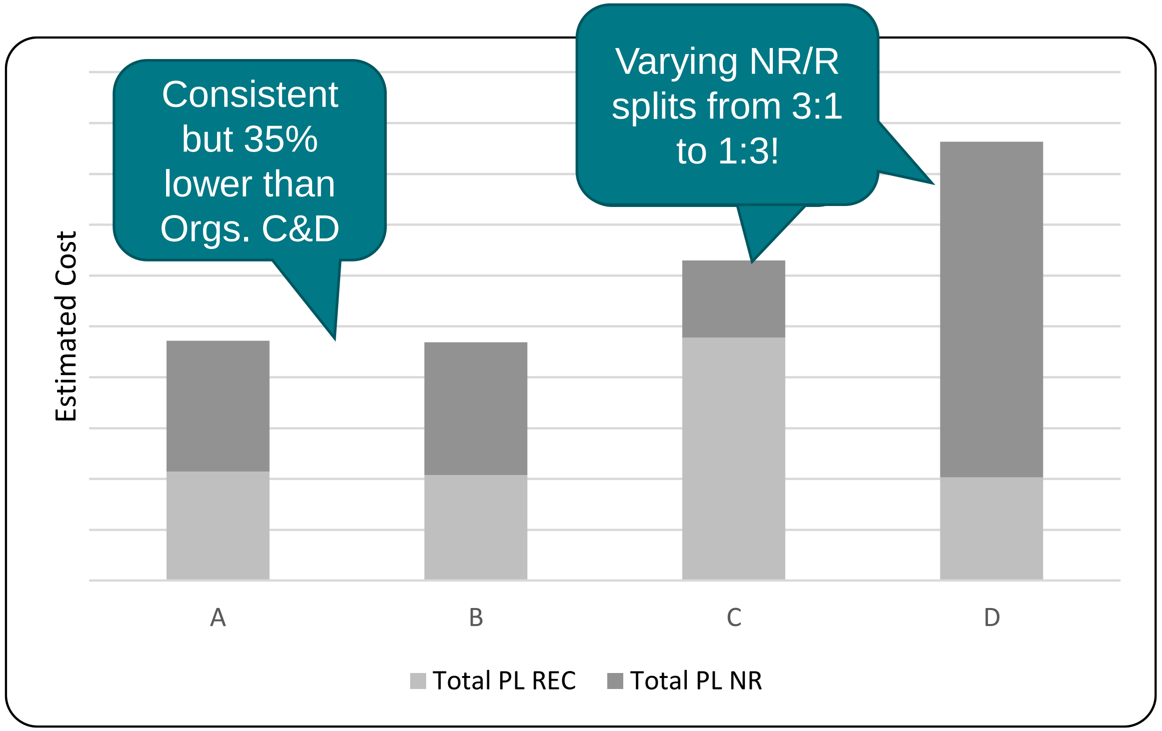


Case Study 2: Communications Payload

- For Case Study 2: team estimated the cost of communications mission payload
- Boxes include data storage unit, commanding, waveguides, receivers, antenna and antenna boom
- Discovered extreme differences in estimates and NR to R ratios, which are representative of the amount of design work

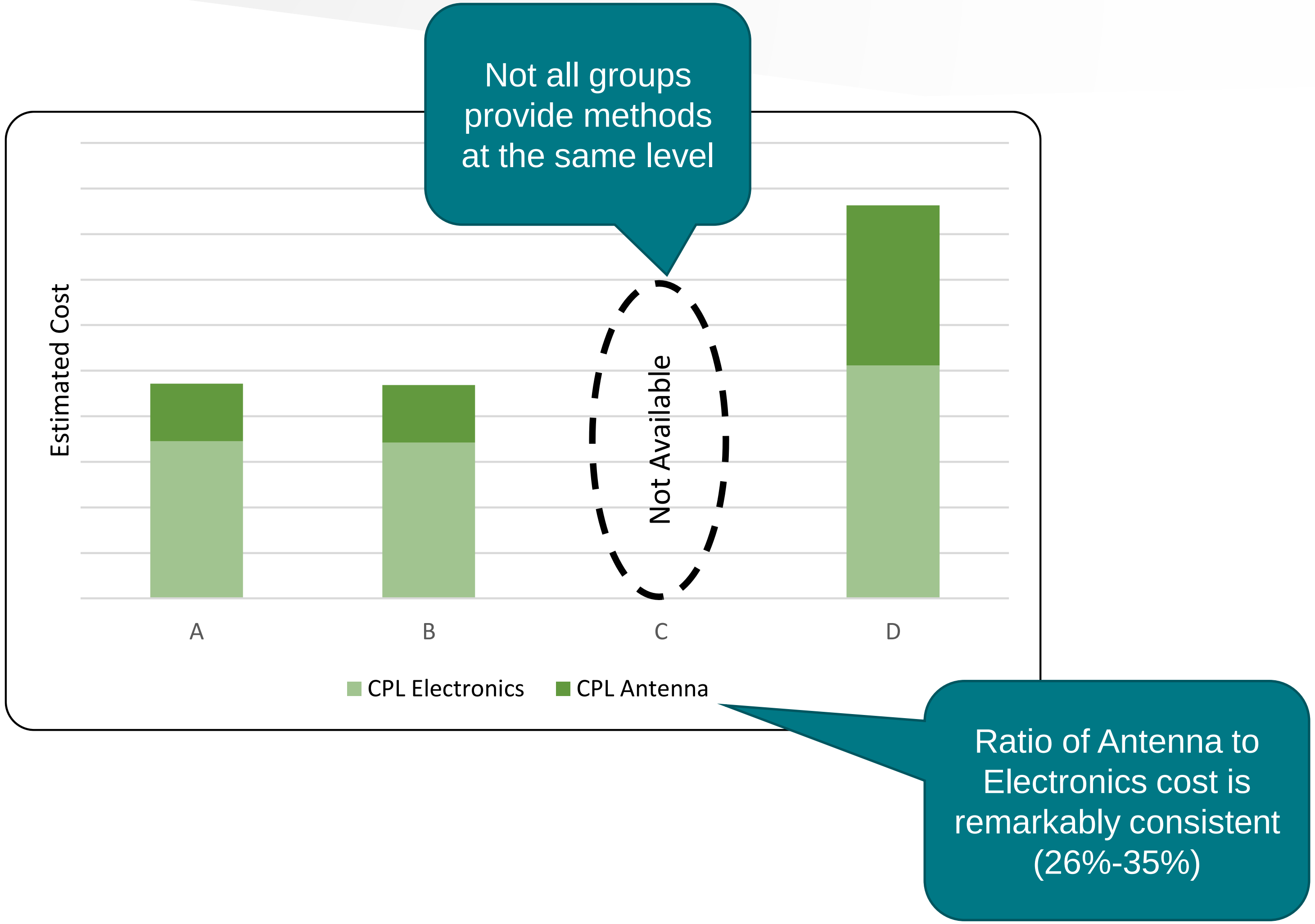
Comm Payloads
WB Comm Electronics
Data Storage Unit
CPL Command Unit
CPL Waveguide
CPL TWTA
CPL Passive Signal Flow Control
CPL Receiver
CPL Frequency & Timing Unit
WB Comm Structure
CPL Pallet & Enclosure
Antenna Boom
CPL Antenna Dish
CPL Antenna Feed
CPL Gimbal Assembly





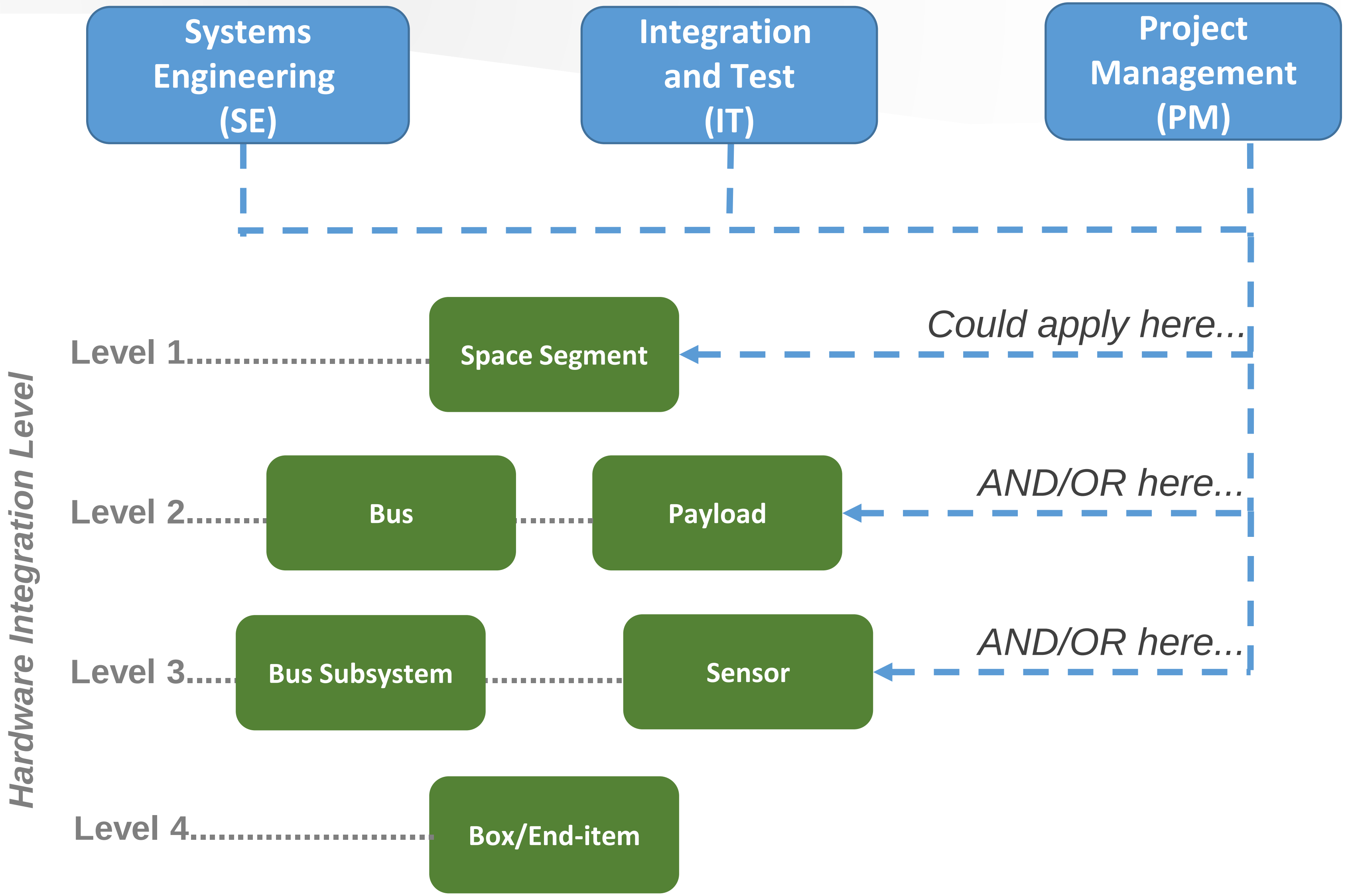
Case Study 2: Communications Payload

- Discovered A and B appear to estimate in similar way, C could not break out at this level, and D was considerably higher



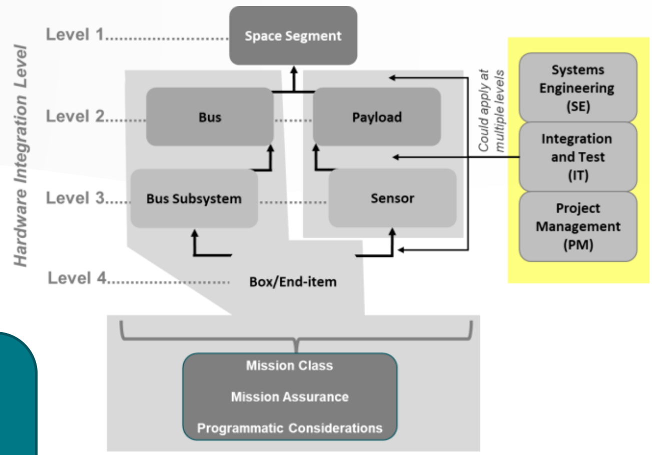
Case Study 3: Space System Levels of Integration

- For Case Study 3: team estimated the cost of SE/IT/PM
- Case Study 3 leverages Case Studies 1 and 2 since these costs add on to bus and payload levels
- SE/IT/PM costs are challenging because they apply at all levels and different orgs book differently

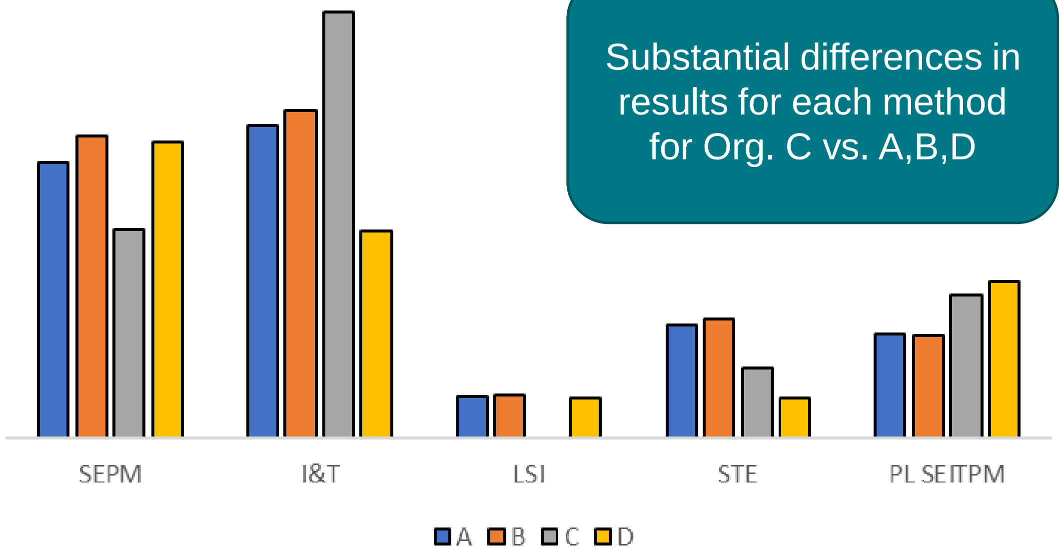


Case Study 3: SEITPM

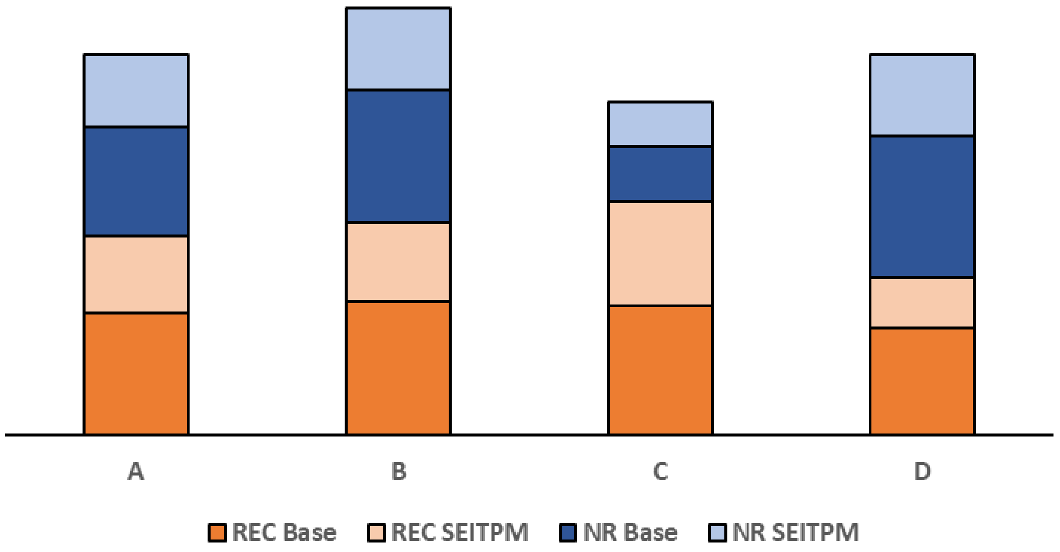
- Discovered large differences in booking between various levels for Org C compared to all other organizations
- In total, the estimate deltas actually (unexpectedly) smoothed out a bit when layering on SEITPM
- **This *may* indicate large normalization differences between organizations – worthy of further study**



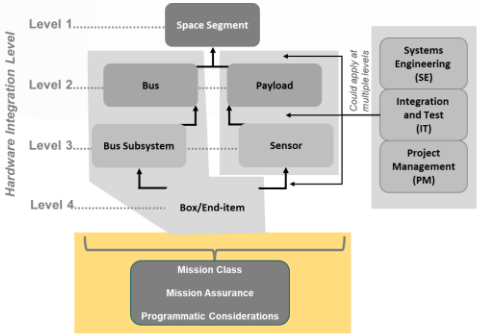
Substantial differences in results for each method for Org. C vs. A,B,D



Total estimates converge ***after*** adding SEITPM rather than compared to just REC and NR base



Case Study 4: Mission Assurance/Class



- For Case Study 4: team examined effect of mission assurance and mission class on cost
- Case Study 4 leverages Case Studies 1, 2 and 3 – an entire satellite!
- Treatment of mission class for estimates
  - Some organizations do not address mission class at all in their methods
  - Some organizations treat class as an independent variable in CERs
  - Others handle with complexity factor
- Adjustments based on mission assurance can reduce estimate by up to 80%!!

Considerations for Class A - Class D NASA Missions and Instruments

Mission and Instrument Risk Classification Considerations		
Priority (Relevance to Agency Strategic Plan, National Significance, Significance to the Agency and Strategic Partners)	Very High:	Class A
	High:	Class B
	Medium:	Class C
	Low:	Class D
Primary Mission Lifetime	Long, > 5 Years:	Class A
	Medium, 5 Years > – > 3 Years:	Class B
	Short, 3 Years > – > 1Years:	Class C
	Brief, < 1 Year:	Class D
Complexity and Challenges (Interfaces, International Partnerships, Uniqueness of Instruments, Mission Profile, Technologies, Ability to Reservice, Sensitivity to Process Variations)	Very High:	Class A
	High:	Class B
	Medium:	Class C
	Medium to Low:	Class D
Life-Cycle Cost	High :	Class A
	Medium to High	Class B
	Medium :	Class C
	Medium to Low	Class D

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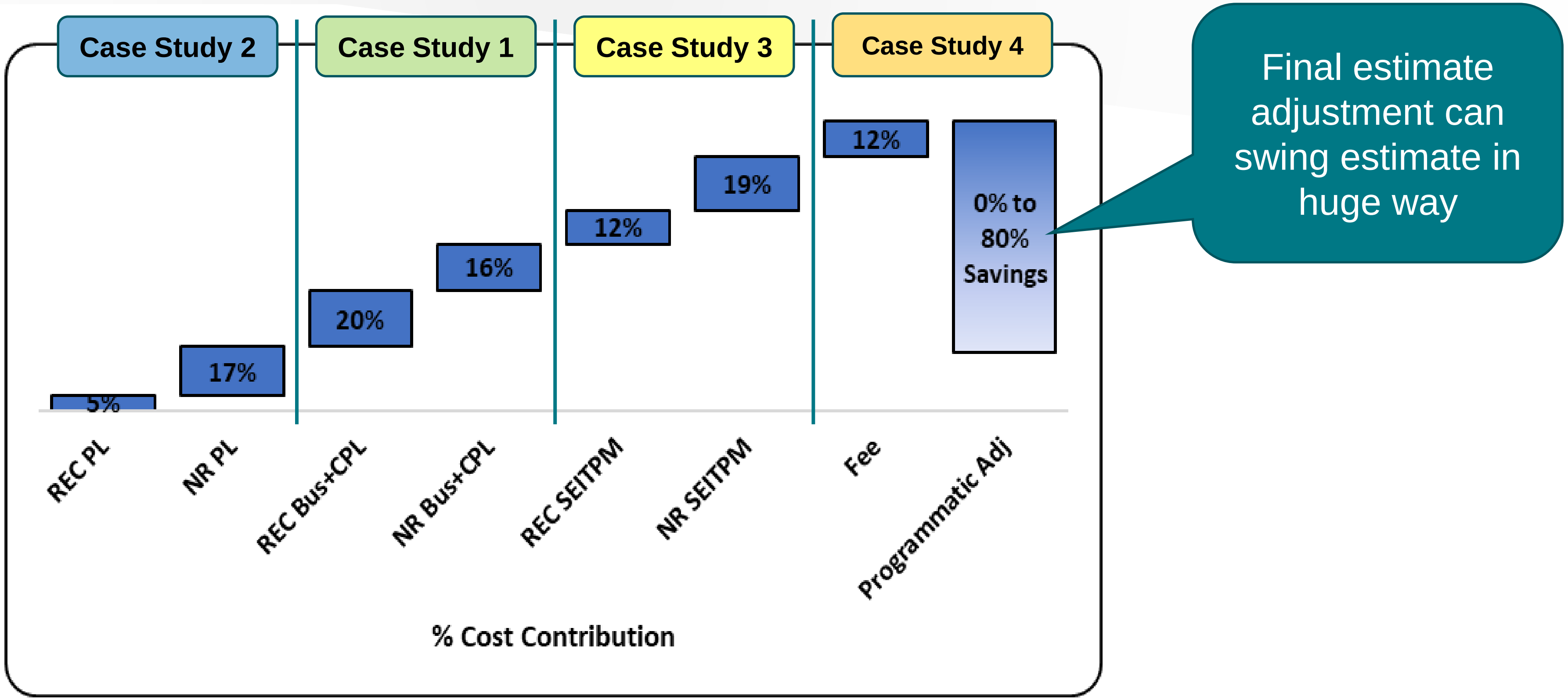
Combining All Four Case Studies



- All the various pieces of the estimate contribute to total cost in a big way
- Critically important to understand *what* is being procured and *how*
- These case studies are not done in a vacuum!
  - Errors are related and additive

De-fragment industry forums such as CIPTs

Share methods (and access guidance) when non-proprietary

Share tools and models when non-proprietary

What Can Be Done to Enhance Collaboration?

Adopt a consolidated normalization guide and Standard WBS

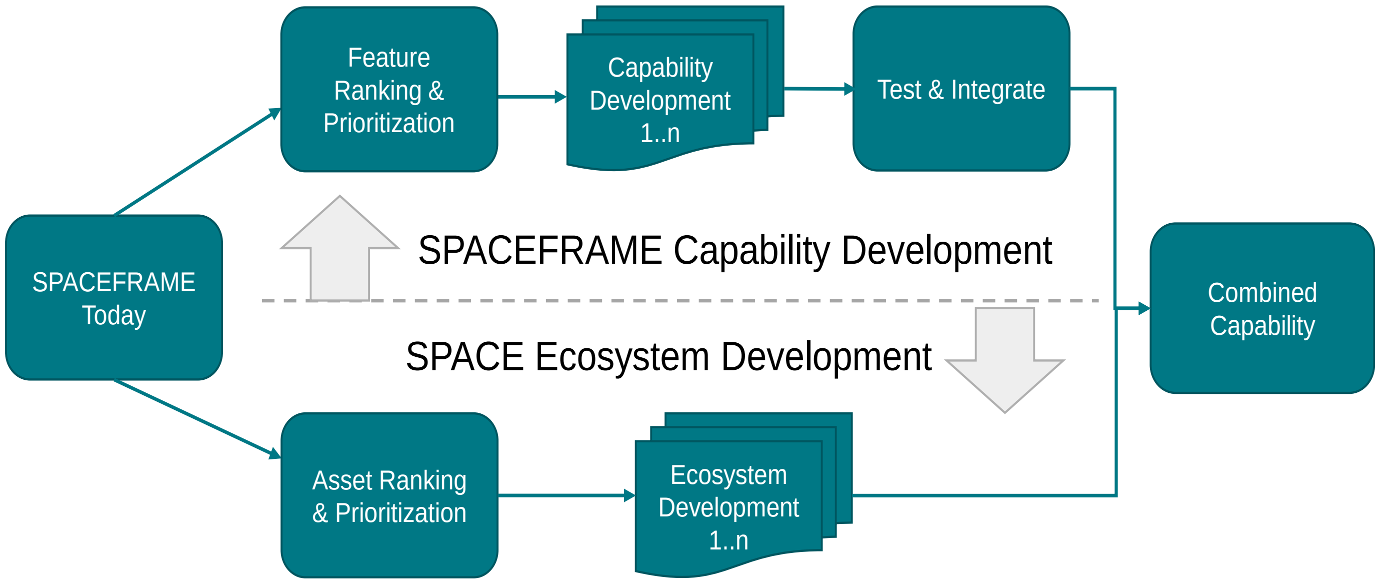
Follow best practices for Method Development (see backup slide)

Benefits of A Standardized Framework

BENEFIT	IMPACT
Intra-Company	
Supplement to existing training content on parametrics and cost models	More relevant training; faster on-boarding to space systems projects
A basis for a Space Systems Community of Practice	More standardized support and improved base capabilities
Intra-Agency/Office	
Established tool for clients without a native parametric estimating capability	**~6+** month improvement vs. 'from-scratch' model development
Adaptable, customizable framework for clients with a native parametric estimating capability	**~50%** improvement in updating existing client-specific models
Efficient development of AoAs & other trades	Clients without current AoA capability will have it by default
Intra-Community	
Recommendations for methods sharing and community adoption	Help clients increase their influence in the space community

Takeaway & Next Steps

- Development of SPACEFRAME and results of case studies show clear need for transparent estimating methods to enable collaboration



- Moving forward, team focus is on the following:
  - Ecosystem development to enable further modeling work
    - Data Collection Policy, Data Structuring, Automated Methods Updates/Development
  - 'Space Estimator' training enabling scalability; educate customers and new analysts alike

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Questions?

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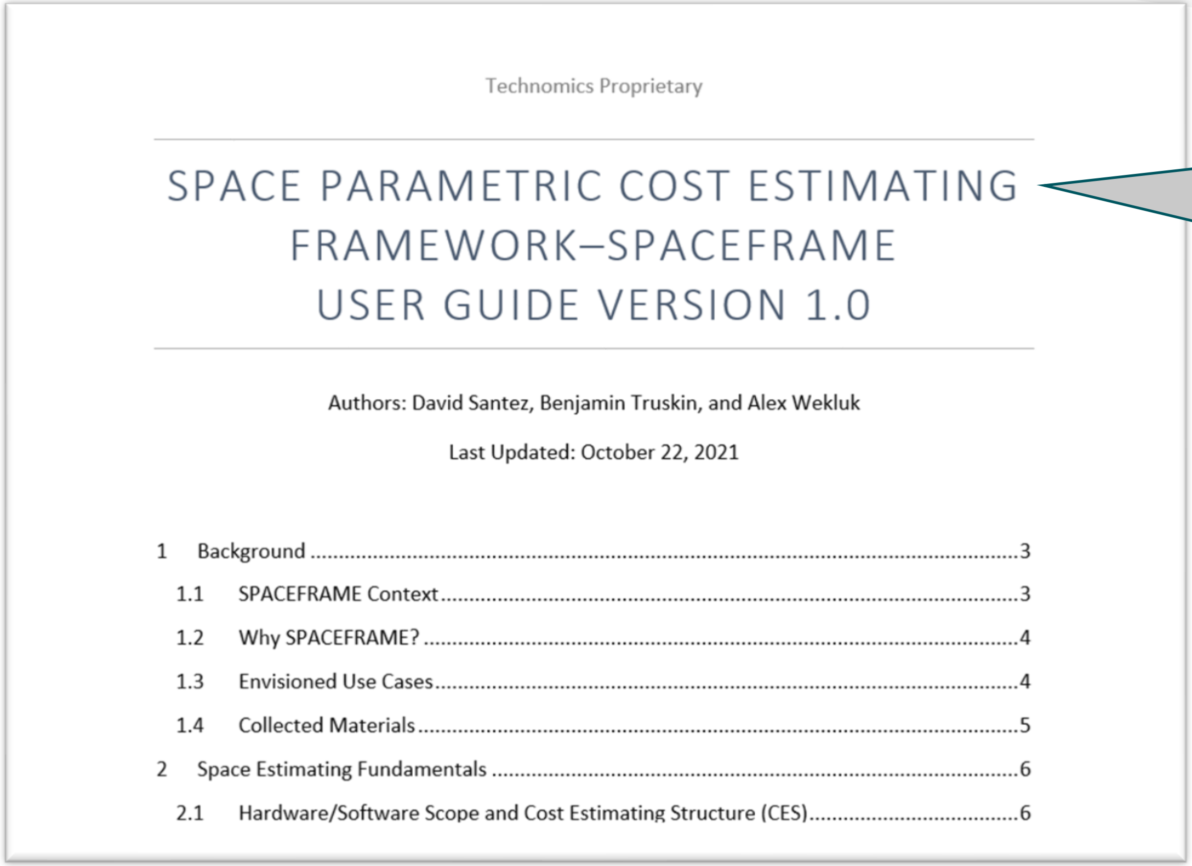
Excel Isn't Everything


Technomics Proprietary

SPACE PARAMETRIC COST ESTIMATING FRAMEWORK–SPACEFRAME USER GUIDE VERSION 1.0

Authors: David Santez, Benjamin Truskin, and Alex Wekluk

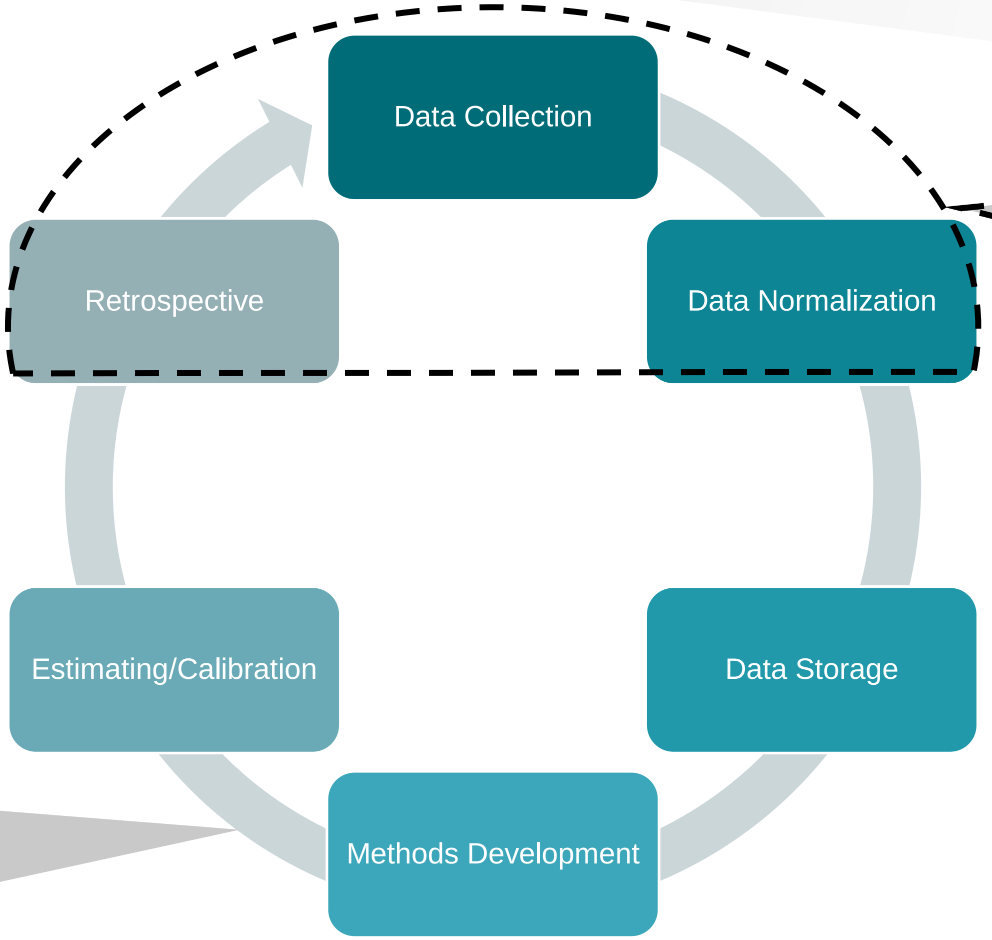
Last Updated: October 22, 2021

1 Background 3
1.1 SPACEFRAME Context 3
1.2 Why SPACEFRAME? 4
1.3 Envisioned Use Cases 4
1.4 Collected Materials 5
2 Space Estimating Fundamentals 6
2.1 Hardware/Software Scope and Cost Estimating Structure (CES) 6

- 50+ pages of goodness!
- Detailed explanations of functionality
- Example Walkthroughs
- Term Glossary

Early focus on the User Guide provides long term benefits to developing capability, training analysts

Our POV - Transparent Data Flywheel



Groups that don't invest here become reliant on black box models

Positive feedback loop!

Investment somewhere makes improvements easier everywhere

Best Practices for Methods Development

Accessibility

- Open portal
- Include contact info/instructions on how to get access when engaging community

Normalization Process Control

- To use cost data effectively for methods development, control should be exercised over how it is collected and normalized!
  - Recognize that effectiveness varies by organizational framework

Variable Definitions

- Clearer definitions (e.g. ‘Power’ vs. ‘Maximum Transmission Power’)
- Scope of costs (e.g. ‘$ = …’ vs. ‘Total REC Cost Phase A-D BY20$k = …’)
- Dataset ranges where possible to avoid misapplication

Context

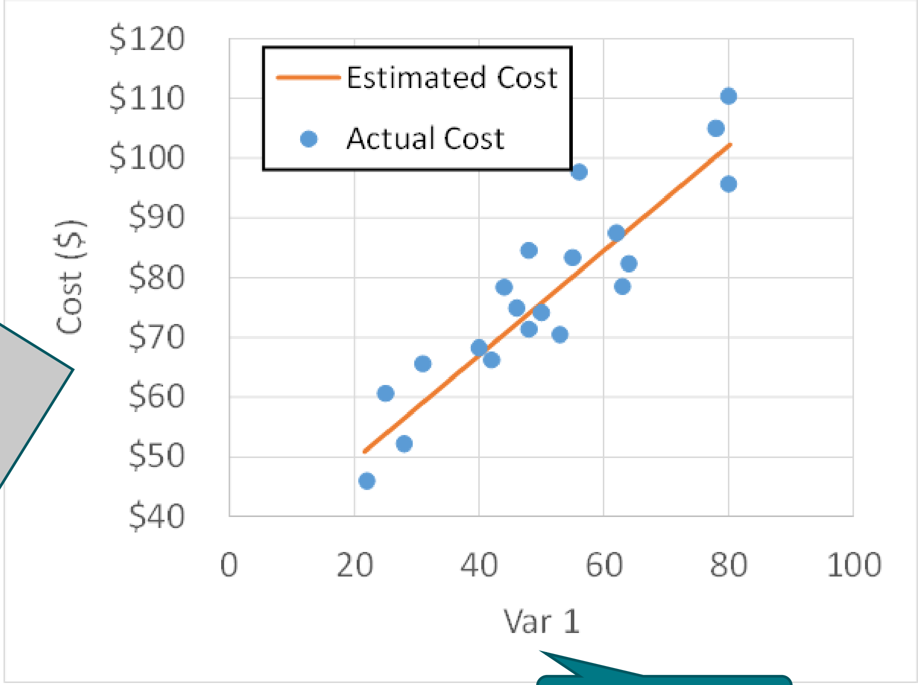
- Why was the method developed and what was the intended use case?
- Were omissions to the method done purposefully?
- Does the CER rely on another sub-model as input?

Parametrics Depicted

Example CER Publishing Document

CER	Recurring Cost: Widget X	
Date Developed	January 2023	
Scope	The scope of this CER is limited to widgets of type X that are used in earth-orbiting applications. Excludes widgets for deep-space missions.	
Functional Form	AUC (BY2023$k) = $a*Wt^{b}*BPC^{c}*d^{Class\ A/B}$	
Definitions	**Variable**	**Definitions**
	Wt	Weight of measured in lbs
	BPC	Quantity of units built
	Class A/B	Stratifier value if Mission Assurance Class is NASA Category A or B then 1; else 0
Standard % Error	60%	
Average Bias	0.0%	

Graphically



e.g. Weight

CERs provide consistent, credible, customizable method of estimating systems early in lifecycle

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