JCL Analysis for Preliminary Design Phases of Future Lunar Missions & Programs

NASA Cost & Schedule Symposium

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Presentation Overview

- Introduction
- JCL / CASCoM Overview
- CASCoM Features & Applications
- Applying CASCoM to Lunar Mission Architectures
- Wrap-up / Questions

SpaceWorks Overview | Advanced Development

Concept Definition

- Concept of Operations
- “Level-0” analysis
- Sketches & storyboards

Concept Trade Studies

- Analysis of Alternatives
- Mission or system-level trades
- Performance and cost impacts

System Design & Evaluation

- Requirements development
- High-fidelity engineering analyses
- Technical illustration



Probabilistic Analysis

- Uncertainty quantification
- Monte Carlo simulation
- Risk assessment and robust design

Multidisciplinary Design Optimization

- Integrated workflow / digital thread
- Responsive models and metamodels
- Mission or system-level optimization

Technology Prioritization

- SME interviews and elicitation
- Performance, cost, and schedule assessments
- Portfolio optimization

JCL Overview

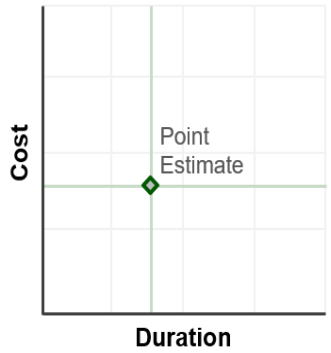
JCL [1] *noun*:

a. The probability that cost will be equal to or less than the targeted cost AND schedule will be equal to or less than the targeted schedule date

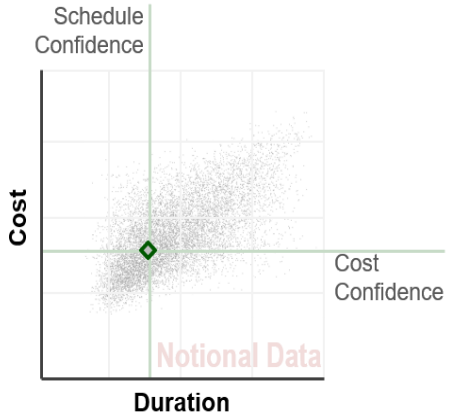
b. A process and product that helps inform management the likelihood of a project's programmatic success

c. A process that combines a project's cost, schedule, and risk into a complete picture

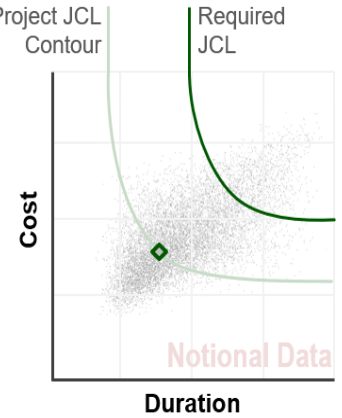
Point Estimate:



After Probabilistic Analysis:



After JCL Analysis:



Why use JCL?

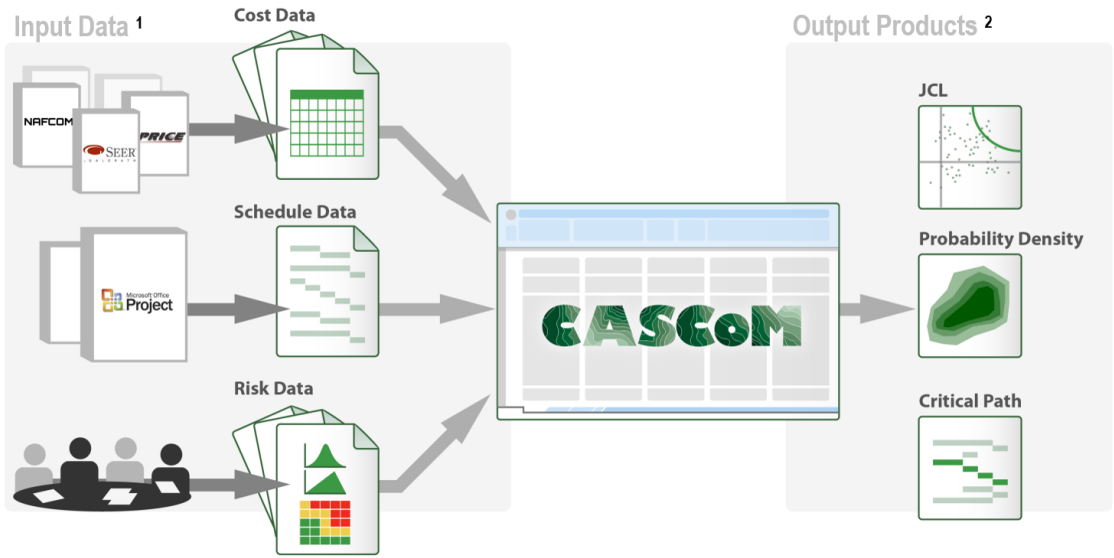
- It's consistent with project realities
  - Total cost and total schedule duration are high-profile metrics, or even hard constraints, for a project
  - Cost and duration are often dependent on one another in the context of a project
  - Assessing risk and uncertainty in cost and duration jointly gives a more complete description of project execution confidence
- It provides valuable information
  - Reveals the magnitude (and timing) of potential funding or schedule modifications required to reach acceptable confidence from initial project position
  - Highlights possible and probable critical paths within project schedule

SpaceWorks' CASCoM Tool | History & Rationale for Development

- The **Cost and Schedule Confidence Model (CASCoM)** was designed to facilitate joint confidence level analysis early in the project life cycle. The application uses Monte Carlo methods and combines cost, schedule, and risk data, with uncertainty, to generate joint probability distributions.

- CASCoM was originally developed by SpaceWorks under a NASA contract in 2012-2013 with additional development completed in 2015 under a second NASA task order
  - Software was added to NASA's cost estimation toolset and should still be available to NASA users

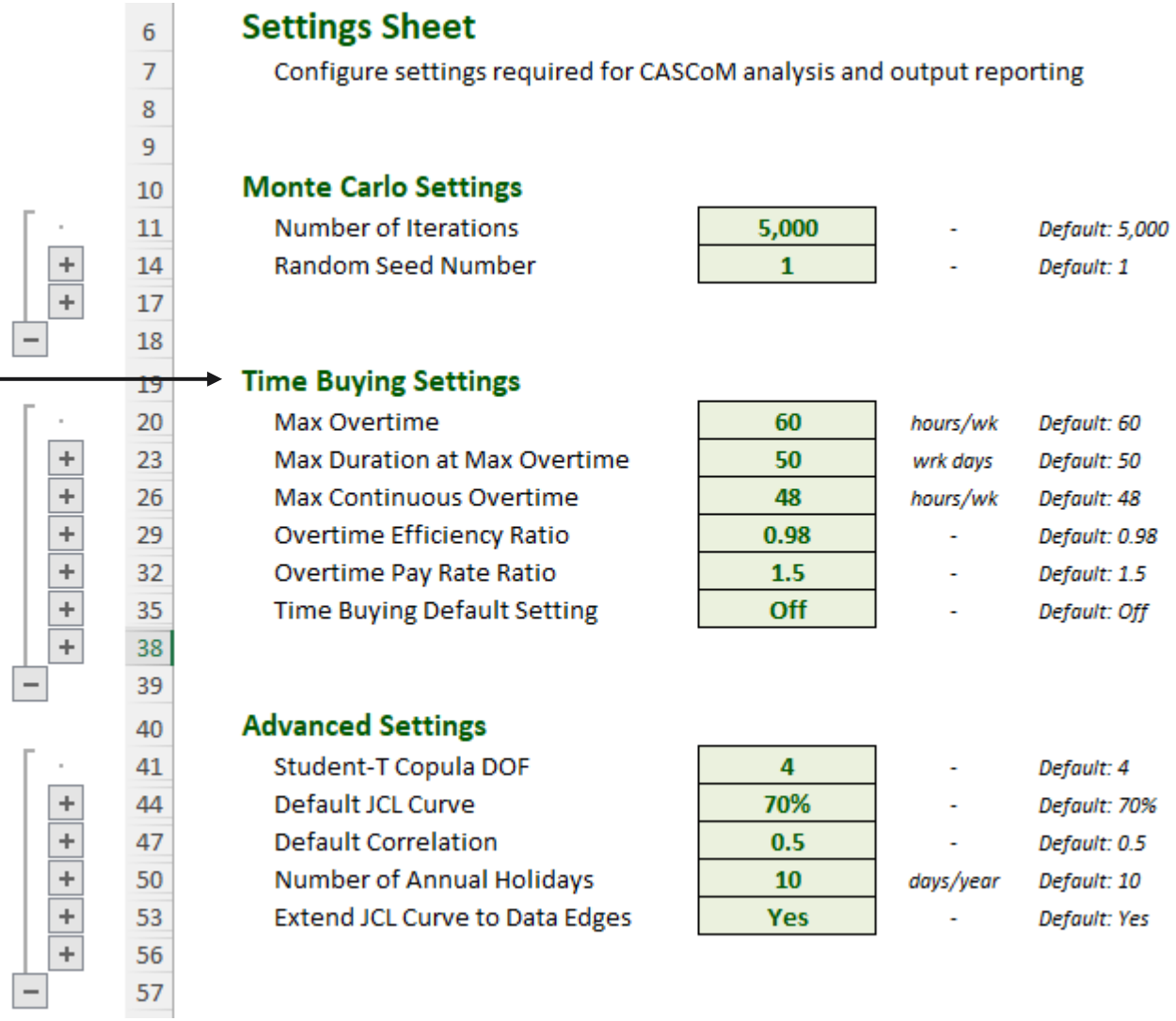
- CASCoM is meant to complement other JCL tools and provide quick analysis early to better inform analysis and decision making later



CASCoM Features

Cost, Schedule, and Risk Inputs

- Distributions
  - None (current best estimate)
  - Uniform (min/max)
  - Triangular (least/likely/most)
  - Log-Normal (mean/std dev)
- Schedule Dependencies
  - Fixed Start Date
  - Start-to-Start
  - Finish-to-Start (one or multiple dependencies)
  - Later of (fixed date or precedent element)
- Risk Factors
  - Impacted Element
  - Likelihood
- Time Buying (pay more to decrease schedule)



Settings Sheet

Configure settings required for CASCoM analysis and output reporting

Monte Carlo Settings

Number of Iterations	5,000	-	*Default: 5,000*
Random Seed Number	1	-	*Default: 1*

Time Buying Settings

Max Overtime	60	*hours/wk*	*Default: 60*
Max Duration at Max Overtime	50	*wrk days*	*Default: 50*
Max Continuous Overtime	48	*hours/wk*	*Default: 48*
Overtime Efficiency Ratio	0.98	-	*Default: 0.98*
Overtime Pay Rate Ratio	1.5	-	*Default: 1.5*
Time Buying Default Setting	Off	-	*Default: Off*

Advanced Settings

Student-T Copula DOF	4	-	*Default: 4*
Default JCL Curve	70%	-	*Default: 70%*
Default Correlation	0.5	-	*Default: 0.5*
Number of Annual Holidays	10	*days/year*	*Default: 10*
Extend JCL Curve to Data Edges	Yes	-	*Default: Yes*

CASCoM Applications

- Although originally motivated by the need to analyze spacecraft development projects, CASCoM is generally applicable to any project that can be defined as a collection of tasks with associated cost and duration
- As such, SpaceWorks has leveraged CASCoM for a variety of advanced concepts and early-stage design projects ranging from…

Hypersonic Systems



Image credit: SpaceWorks

Spacecraft



Image credit: SpaceWorks

Mission Architectures & Operations

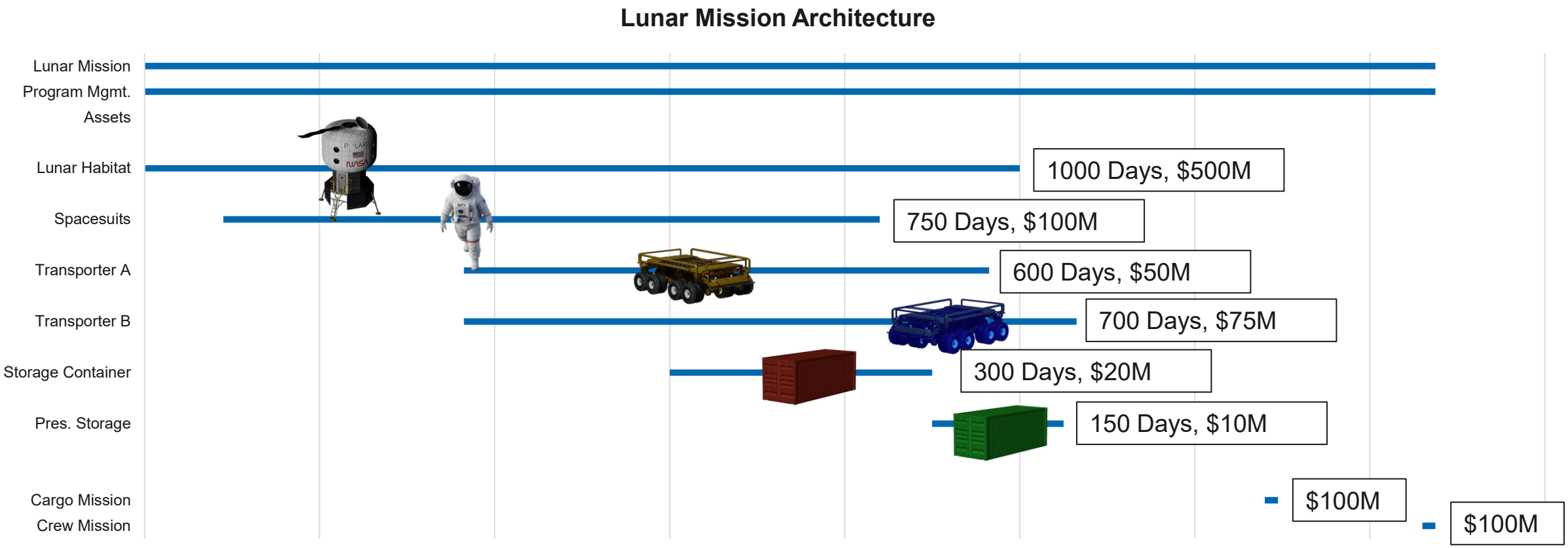


Image credit: NASA

Images are representative to show types of projects rather than specific projects worked

Lunar Mission Architecture

- There are many systems and subsystems required to perform a campaign of lunar missions
- However, for the purposes of this presentation, we are only going to focus on a select few assets to keep things simple and look at their development cost and schedule



Architecture Characteristics

- For this analysis, we'll assume there is a Cargo Mission to get some assets in place before a Crew Mission

- Key considerations:
  - **Cargo Mission** will carry Lunar Habitat, Transporter A, and Unpressurized Cargo Containers
  - There will be a 1-2 month post-mission assessment period to address any issues or upgrades
  - **Crew Mission** will then carry Spacesuits, Transporter B, and Pressurized Cargo Containers
  - Both missions have 'target launch dates' and will either launch then or when all precedent assets are ready (whichever comes second)
  - **Transporters** are treated as a dual/parallel development program
    - Transporter A – Lower cost/schedule but greater uncertainty
    - Transporter B – Higher cost/schedule but less uncertainty
  - **Storage Containers** are treated as a staged development program
    - Unpressurized – initial development effort
    - Pressurized – follow-on effort to unpressurized container

CASCoM Inputs

Note: For this example, all cost and schedule numbers are notional

Set element types

For support elements, cost is determined based on Labor Rate and duration is set by its dependency

Established dependencies for all elements

For fixed dates, formulas can be used

Cost and Schedule distributions are defined

Cost distribution does not have to be the same as schedule distribution

Decide how related cost and schedule are for a given element

Time Buying enables overtime (reducing schedule but increasing cost)

WBS Elements		WBS Element Type			Schedule Dependencies			Cost Distribution Inputs ($K)				Schedule Distribution Inputs (wrk days)				Other	
ID	Description	Element Type	Support Link	Labor Rate ($K/wrk day)	Dependency Type	Predecessor Task	Fixed Start Date	Cost Distribution	Cost MEV	Cost Param B Uniform - Min Triangle - Min Log-N - Mean	Cost Param C Uniform - Max Triangle - Max Log-N - Std Dev	Duration Distribution	Duration CBE	Duration Param B Uniform - Min Triangle - Min Log-N - Mean	Duration Param C Uniform - Max Triangle - Max Log-N - Std Dev	Correlation	Time Buying
0	Lunar Mission	-	-	-	Fixed Start	-	1/1/2027	-	-	-	-	-	-	-	-	-	-
1	Program Mgmt.	Support	0	10	Fixed Start	-	-	None	0	-	-	None	-	-	-	0.5	Off
2	Assets	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.1	Lunar Habitat	Standard	-	-	Start-to-Start	0	-	Log-Normal	500000	500000	50000	Log-Normal	1000	1000	100	0.5	Off
2.2	Spacesuits	Standard	-	-	Fixed Start	-	4/1/2027	Uniform	100000	100000	150000	Uniform	750	650	1000	0.5	Off
2.3	Transporter A	Standard	-	-	Fixed Start	-	1/1/2028	Triangle	50000	45000	100000	Triangle	600	550	850	0.5	Off
2.4	Transporter B	Standard	-	-	Fixed Start	-	=I7+365	Triangle	75000	56250	93750	Triangle	700	600	750	0.5	Off
2.5	Storage Container	Standard	-	-	Fixed Start	-	8/23/2028	Uniform	20000	18000	22000	Uniform	300	270	330	0.5	Off
2.6	Pres. Storage	Standard	-	-	Finish-to-Start	2.5	-	Triangle	10000	5000	15000	Triangle	150	75	225	0.5	Off
3	Cargo Mission	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3.1	Target Launch	Standard	-	-	Fixed Start	-	7/4/2030	None	0	-	-	None	0	-	-	0.5	Off
3.2	Actual Launch	Standard	-	-	Finish-to-Start	2.1,2.4,2.5,3.1	-	None	100000	-	-	Uniform	15	14	17	0.5	Off
3.3	Post-Mission Analysis	Standard	-	-	Finish-to-Start	3.2	-	None	50000	-	-	Uniform	60	30	60	0.5	Off
4	Crew Mission	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.1	Target Launch	Standard	-	-	Fixed Start	-	12/31/2030	None	0	-	-	None	0	-	-	0.5	Off
4.2	Actual Launch	Standard	-	-	Finish-to-Start	2.2,2.3,2.6,3,4.1	-	None	100000	-	-	Uniform	15	14	17	0.5	Off

All costs are $K

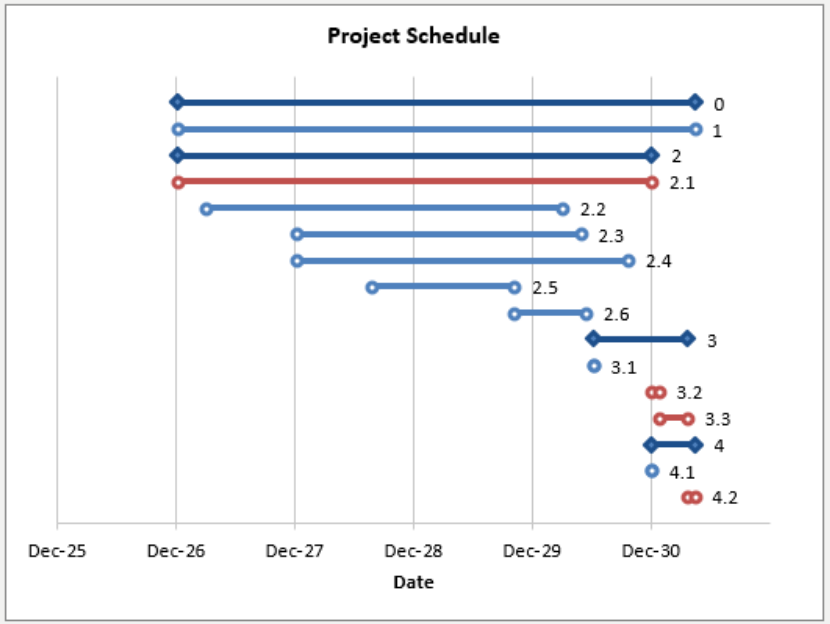
All durations are Workdays

Point Estimate

- Based on current best estimate inputs and dependencies, CASCoM generates a project schedule and identifies the critical path (red lines) for your project
- This allows for initial insight into how efforts should be scheduled
  - Here, the Lunar Habitat (2.1) is on the critical path with it, as well as Transporter B (2.4), surpassing the Target Cargo Launch Date

Lunar Mission - Point Estimate Results
NCSS Presentation

The Point Estimate represents the current Budget and Project Plan



*Red denotes nominal critical path

ID	Description	Terminal	Critical Path	Cost	Start Date	Cal Days	End Date
0	Lunar Mission	No	No	1,015,900	1/1/2027	1,591	5/11/2031
1	**Program Mgmt.**	**Yes**	**No**	**10,900**	**1/1/2027**	**1,591**	**5/11/2031**
2	**Assets**	**No**	**No**	**755,000**	**1/1/2027**	**1,460**	**12/31/2030**
2.1	Lunar Habitat	Yes	Yes	500,000	1/1/2027	1,460	12/31/2030
2.2	Spacesuits	Yes	No	100,000	4/1/2027	1,095	3/31/2030
2.3	Transporter A	Yes	No	50,000	1/1/2028	876	5/26/2030
2.4	Transporter B	Yes	No	75,000	1/1/2028	1,022	10/19/2030
2.5	Storage Container	Yes	No	20,000	8/23/2028	438	11/4/2029
2.6	Pres. Storage	Yes	No	10,000	11/4/2029	219	6/11/2030
3	**Cargo Mission**	**No**	**No**	**150,000**	**7/4/2030**	**290**	**4/19/2031**
3.1	Target Launch	Yes	No	0	7/4/2030	0	7/4/2030
3.2	Actual Launch	Yes	Yes	100,000	12/31/2030	22	1/21/2031
3.3	Post-Mission Analysis	Yes	Yes	50,000	1/21/2031	88	4/19/2031
4	**Crew Mission**	**No**	**No**	**100,000**	**12/31/2030**	**131**	**5/11/2031**
4.1	Target Launch	Yes	No	0	12/31/2030	0	12/31/2030
4.2	Actual Launch	Yes	Yes	100,000	4/19/2031	22	5/11/2031

Cost: $1,015,900,000
Duration: 1591 Days

The breakout on the right provides cost, duration, and start/end dates that can be used to inform future iterations of the analysis for refinement of project structure

See the difference between Target and Actual launch dates

Monte Carlo of Nominal Lunar Mission Project

Lunar Mission - Monte Carlo Results
NCSS Presentation

Generated by CASCoM v1.1
8/12/2026

Point of Interest

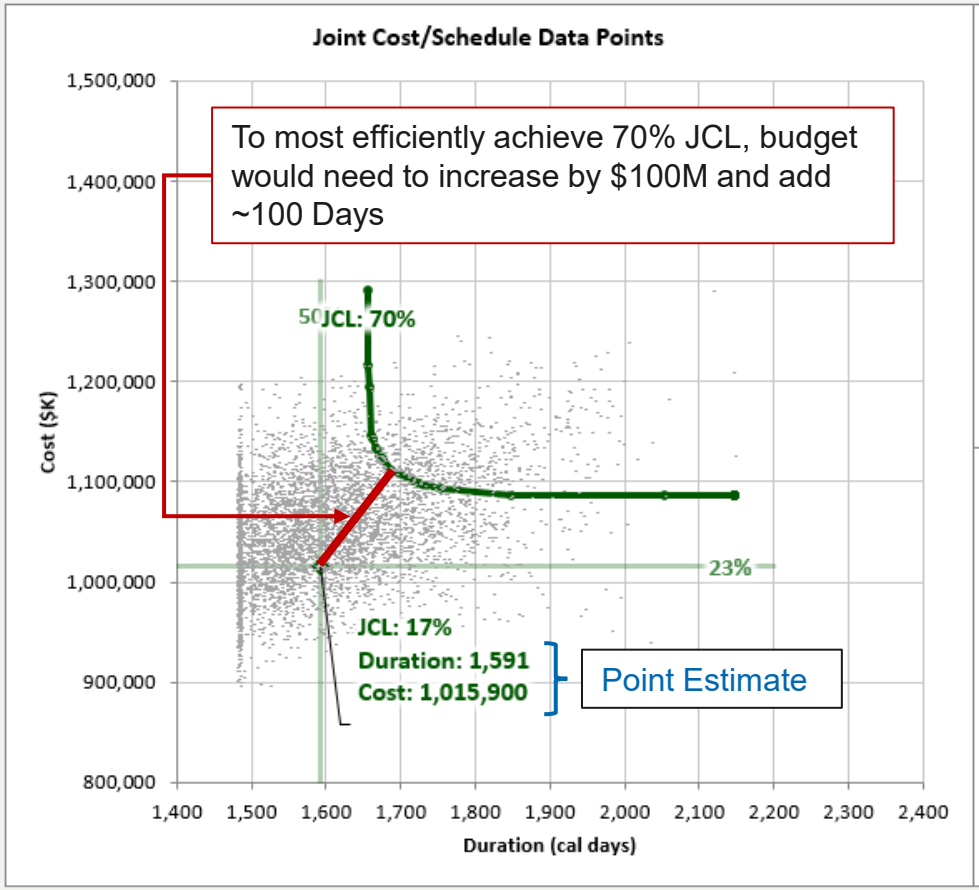
Project Duration:	1,591	cal days
Project Cost:	1,015,900	$K
JCL Curve:	70%	-
Joint Confidence:	16.6%	-
Schedule Confidence:	49.8%	-
Cost Confidence:	22.6%	-

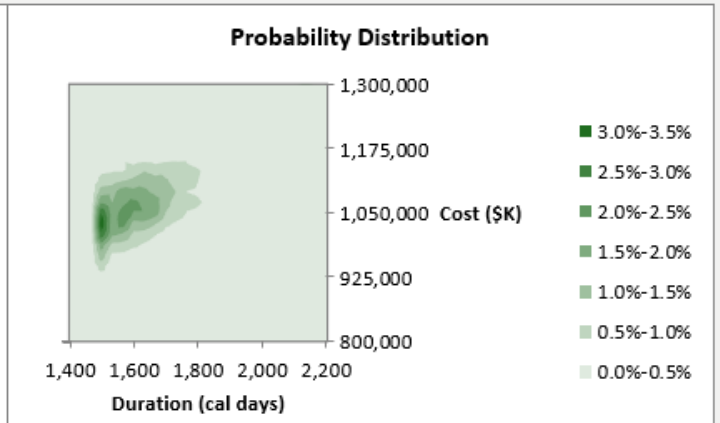
Critical Path Summary

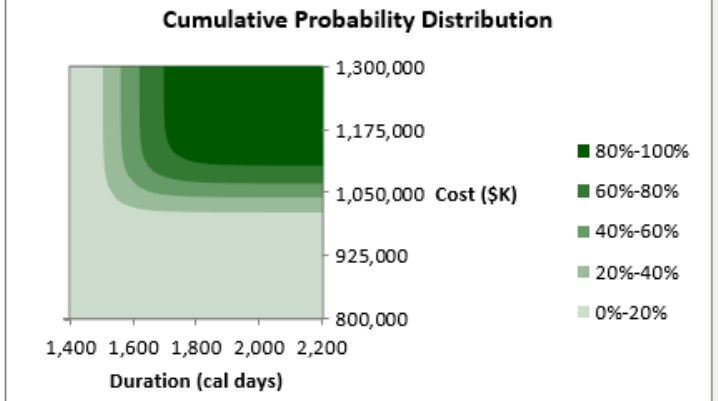
WBS Elements	Frequency
2.1, 3.2, 3.3, 4.2	64.2%
2.3, 3.2, 3.3, 4.2	16.5%
4.1, 4.2	14.1%
2.2, 4.2	5.2%

Threat Summary

Active Threats
-







What if there are Risks not captured by Uncertainties?

- Risks can be added to the Monte Carlo analysis and allow users to assess risks that could significantly impact a work element
  - They can be turned on/off as needed and have inputs similar to cost and schedule

- **Risk 1: Lunar Habitat** structure costs skyrocket because critical material used up by data centers
  - Impacted Element: Lunar Habitat (2.1)
  - Likelihood: 20%
  - Cost Impact: +$160-250M, Uniform
  - Schedule Impact: +30/60/75 Days, Triangular

- **Risk 2: Spacesuits** need more testing because test units had manufacturing defect
  - Impacted Element: Spacesuits (2.2)
  - Likelihood: 40%
  - Cost Impact: +$15/20/30M, Triangular
  - Schedule Impact: +120-210 Days, Uniform

Threat Identification		Threat Inputs		Problem Impact - Cost ($K)				Problem Impact - Schedule (wrk days)				Status	Correlation
Threat Number	Description	Impacts Element ID	Problem Likelihood	Cost Impact Distribution	Cost Impact Param A	Cost Impact Param B	Cost Impact Param C	Duration Impact Distribution	Schedule Impact Param A	Schedule Impact Param B	Schedule Impact Param C	Active	Correlation
1	Habitat Structures Costs Skyrocket	2.1	20%	Uniform	200000	160000	250000	Triangle	60	30	75	Yes	0.5
2	Spacesuits need more testing	2.2	40%	Triangle	20000	15000	30000	Uniform	120	120	210	Yes	0.5
	-	-	-	None	-	-	-	None	-	-	-	Yes	0.5

Add Risks to Monte Carlo Analysis

Lunar Mission - Monte Carlo Results
NCSS Presentation

Impacted data points have increased cost/schedule, reducing JCL of point estimate

Point of Interest

Project Duration:	1,591	cal days
Project Cost:	1,015,900	$K
JCL Curve:	70%	-
Joint Confidence:	11.6%	-
Schedule Confidence:	43.9%	-
Cost Confidence:	16.5%	-

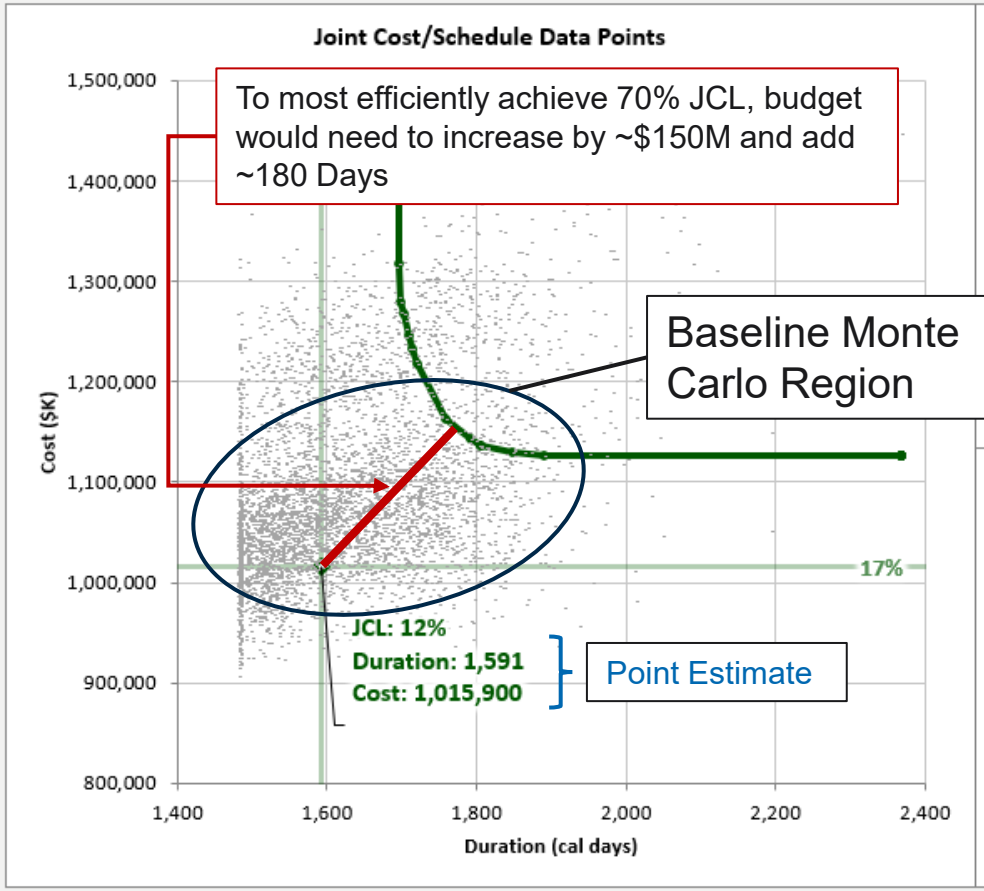
Critical Path Summary

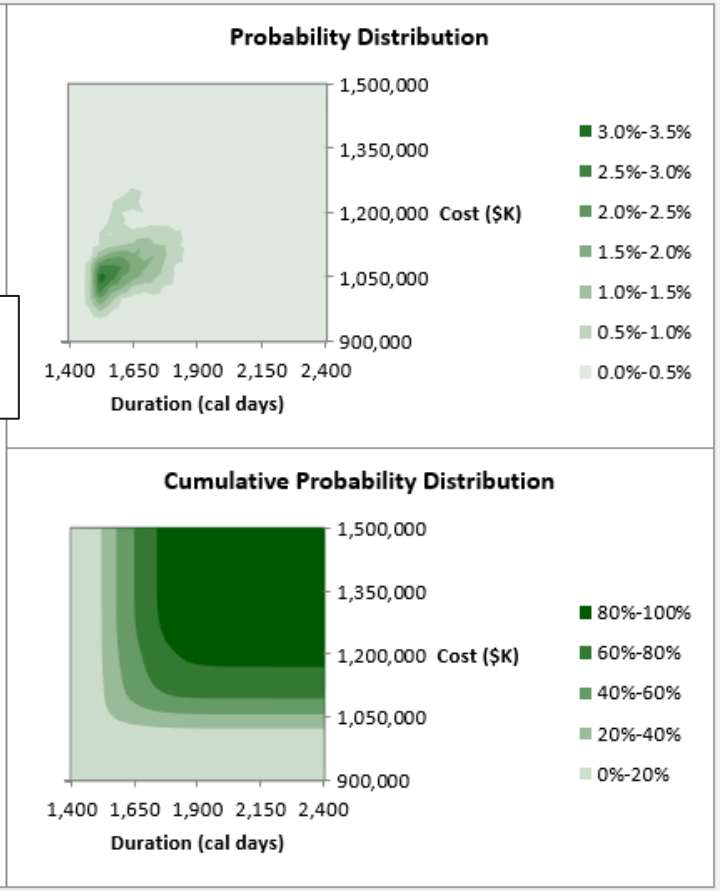
WBS Elements	Frequency
2.1, 3.2, 3.3, 4.2	58.5%
2.2, 4.2	20.0%
2.4, 3.2, 3.3, 4.2	9.9%
4.1, 4.2	7.9%
2.3, 4.2	3.7%

Baseline Critical Path Summary

WBS Elements	Frequency
2.1, 3.2, 3.3, 4.2	64.2%
2.3, 3.2, 3.3, 4.2	16.5%
4.1, 4.2	14.1%
2.2, 4.2	5.2%

Notice the change in the order and frequency of unique critical paths



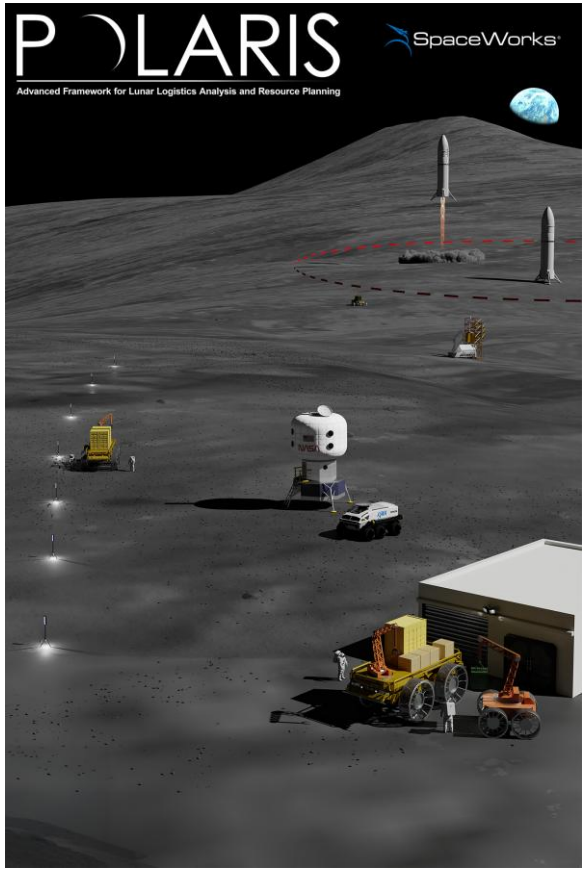


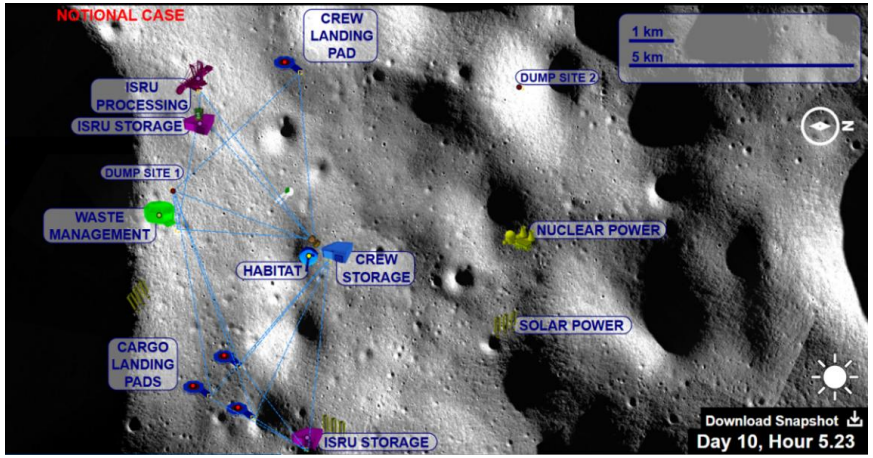
Taking the Next Step with POLARIS

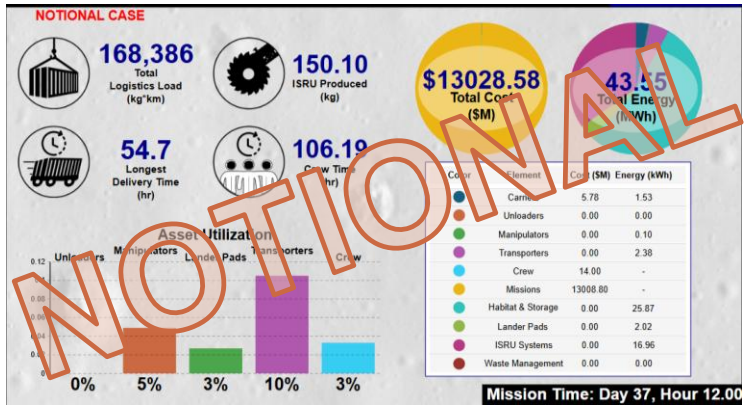
- POLARIS is a modeling and simulation tool for **assessing lunar base operations** based on different configurations and available assets

- Paired with CASCoM, lunar mission architectures can be assessed based on what assets, landers, instruments are ready or needed for given launch dates
  - For example, POLARIS may indicate that Transporter A isn't effective enough for the Cargo Mission and you really need Transporter B instead

- POLARIS mission simulations can also provide cost and duration input data to CASCoM mission elements







Images credit: SpaceWorks

Summary / Wrap-up

- CASCoM is a simple but powerful tool that can be used for early analysis of projects or architectures to assess cost, schedule, and risk

- For Lunar Missions, CASCoM can be used to identify critical path development efforts and assess the viability of executing planned missions on budget and on time
  - Alternative scenarios can be quickly assessed to refine strategic decision making and reduce risks
  - Integration with POLARIS adds additional granularity for lunar base operations and provides insights into what capabilities (power, assets, etc.) are required to execute lunar missions
  - This provides rapid feedback to CASCoM on what elements must be ready before missions take place
  - This could lead to starting certain efforts earlier or applying Time Buying, if budget allows, to decrease duration

- **SpaceWorks continues to leverage CASCoM across projects and is ready to support NASA by providing assessments of early-phase projects or expanding tool capabilities**

Questions

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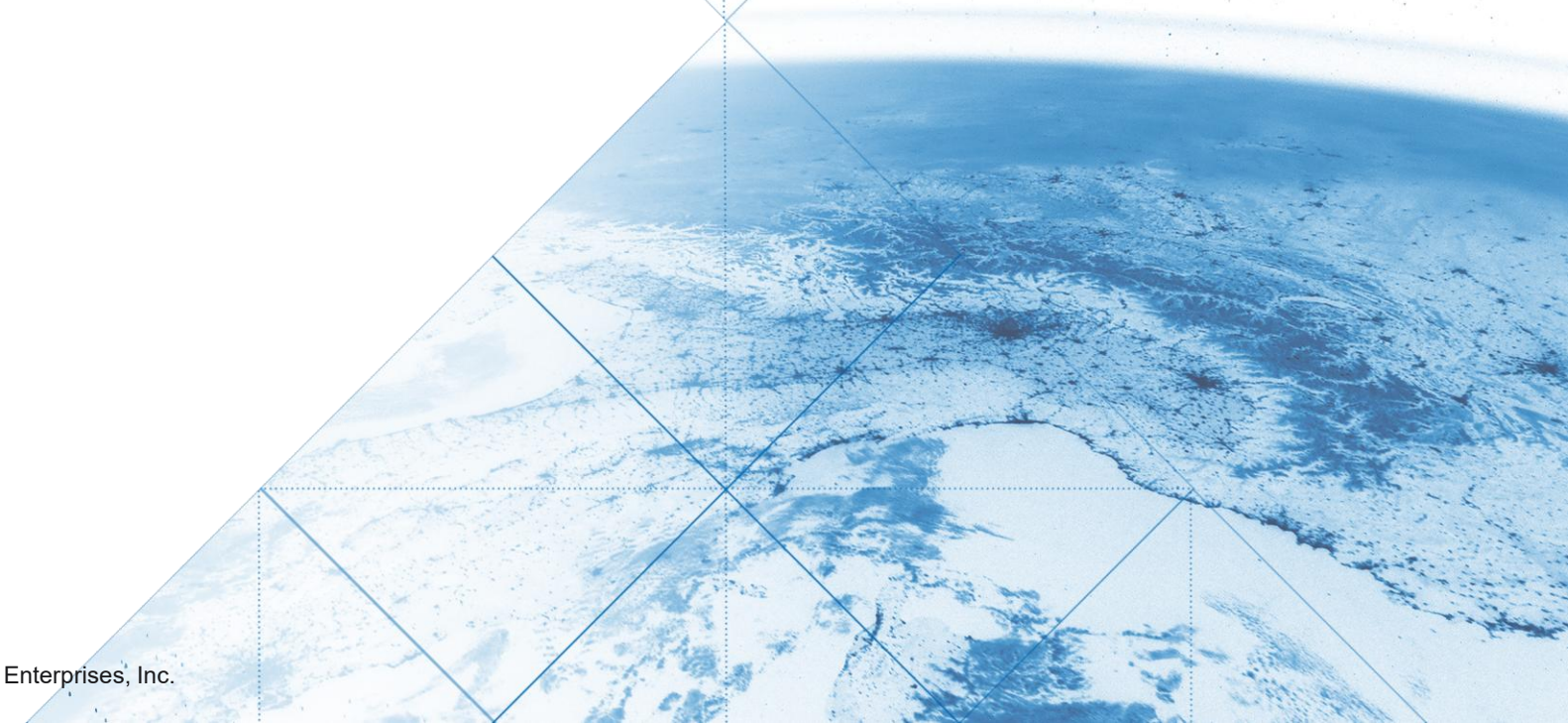

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