Landing Site Engineering Assessment

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February 8, 2017

Overview

- To allow this workshop to focus on science assessment of the candidate landing sites, the project held an engineering telecon last week

- The engineering telecon was intended to expose the science community to:
  - The methods used for assessing the landing sites
  - The maturity of the engineering assessment
  - Summary results for the candidate sites

- Today, we'll focus on the summary results:
  - No sites present unacceptable engineering risk, although certain sites present significant challenges in achieving the full mission objectives
  - Science value will be the primary consideration in down-selection

Landing Safety Assessment

EDL Design Team

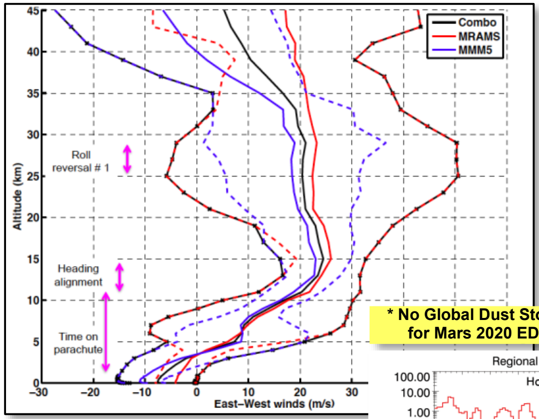
February 8, 2017

EDL Overview

- Since the last landing site workshop in August 2015, TRN has been added to the EDL baseline
- When combined with range trigger, TRN gives the system a significant improvement in landing site accessibility
- Atmosphere and terrain characterization efforts have matured and are on par with the maturity MSL had at final site selection
- All candidate landing sites can be reached with acceptable risk
  - However, the team has less confidence in its assessment for one site

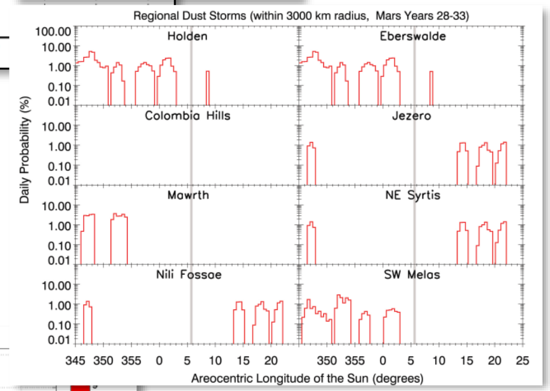
Atmosphere Characterization Progress

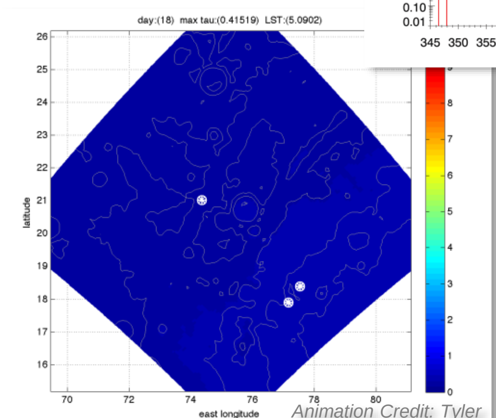
- Ran mesoscale models for new sites emerging from LSW2
  - Eberswalde
  - Columbia Hills
- Ran mesoscale dust storm scenarios for Syrtis region sites
  - Nili Fossae (ran through EDL simulations)
  - Jezero
  - North East Syrtis
- Generated dust storm statistics for Top 8 sites; very low likelihood of a dust event in 2020 landing season
- Delivered assessment of nominal atmosphere for LSW3 sites



* No Global Dust Storm observed for Mars 2020 EDL Season *

Credit: Cantor





Animation Credit: Tyler

Current Mars 2020 CoA status is more mature than MSL at final site selection

Atmosphere Assessment

Site	Atmosphere	Comments
Columbia Hills	(yellow)	• Moderate differences between models • EDL can tolerate more uncertainty at this site
Eberswalde	(green)	
Holden	(green)	
Jezero	(green)	
Mawrth	(yellow)	• Moderate differences between models • EDL can tolerate more uncertainty at this site
North East Syrtis	(green)	
Nili Fossae	(green)	
South West Melas	(orange)	• Noticeable difference in wind profiles between models • Challenging to model this site, i.e. currently lower confidence • Ellipse is placed in tight area • If ellipse was in larger area, then EDL can tolerate more uncertainty

Acceptable EDL performance at Top 8 sites using nominal atmospheres

Will further investigate SWM, MAW, CLH if still considered after LSW3

Terrain Characterization

- Trajectory Monte Carlos using mesoscale atmospheres and system performance uncertainty models inform ellipse sizes
- Ellipse placements balance landed safety (primary concern) and traverse considerations

Landing Site	Lat (degN)	Long (degE)	Approx Elevation (km)	Approx Buffered Ellipse Axes (km)
Columbia Hills	-14.5510	175.4527	-1.95	9.6 x 8.7
Eberswalde	-23.7749	-33.5147	-1.49	8.6 x 7.7
Holden	-26.6130	-34.8167	-2.18	9.5 x 8.1
Jezero	18.4386	77.5031	-2.64	10.7 x 8.3
Mawrth	23.9685	-19.0609	-2.24	11.9 x 9.8
NE Syrtis	17.8899	77.1599	-2.04	11.1 x 8.2
Nili Fossae	21.0297	74.3494	-0.65	9.7 x 7.7
SW Melas	-9.8132	-76.4679	-1.92	9.7 x 8.7

All landing sites achieve landed risk postures in family with MSL

Terrain Hazards Considered

- Rocks
  - Large dangerous rocks identified through HiRISE imagery and smaller dangerous rocks estimated by analytical models
- High slopes
  - Identified through Digital Elevation Models of the environment
- Inescapable areas
  - Fresh craters with non-traversable boundaries
  - Sand ripples that look very challenging for traversal; identified through HiRISE imagery
- Thruster plume interaction
  - Bounding analysis for interaction risk with the thruster plume when landing on a given slope
- Relief over a 2.5km baseline
  - Topographical relief may require more fuel for a safe landing
  - A fuel budget constrains the amount of relief we can mitigate

Maturity of the Terrain Risk Analysis

- All ellipses are well characterized using DEMs, HiRISE images or extrapolated estimates
- No major gaps in terrain knowledge were identified
  - Minor gaps in DEM coverage were examined and their risk was represented using conservative extrapolated slopes
- The risk at these ellipse placements is not expected to fall out of family with MSL
  - Given current atmospheric models
  - Given the current baselined geometry of the rover
- Landing site selection can be driven by the science; EDL can land safely at these locations

EDL Assessment Summary

Site	Atmosphere	Terrain	Overall	Comments
Columbia Hills				Some atmosphere modeling issues identified, but site can tolerate increased ellipse size
Eberswalde				
Holden				
Jezero				
Mawrth				Some atmosphere modeling issues identified, but site can tolerate increased ellipse size
NE Syrtis				
Nili Fossae				
SW Melas				Lack of confidence in atmosphere modeling results coupled with significant terrain hazards bordering the landing ellipse raise concerns

All candidate landing sites are accessible with acceptable risk

Atmosphere modeling issues and tight ellipse placement at SW Melas will present challenges going forward

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Mars 2020 Project

Surface Assessment

Surface Design Team

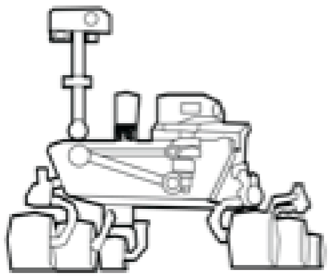
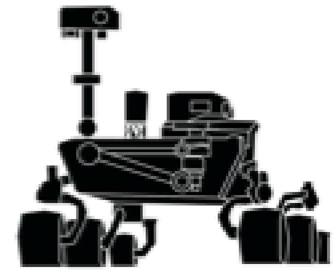
February 8, 2017

Surface Performance Assessment

- Productivity Improvements Summary - Trosper
- Site Specific Traversability Assessment Summary - Ono
- Site Specific Surface Mission Performance - Lange

MSL vs. Mars2020 Mission Comparison

1.25 MARS YEARS
context

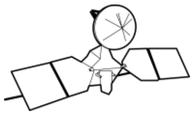
MSL	M2020
	
MARS YEARS: **1.25**	MARS YEARS: **1.25**
DISTANCE COVERED: **10.6 km**	DISTANCE TO COVER: **15 km**
SAMPLES COLLECTED: **2 scooped, 6 drilled samples**	SAMPLES TO COLLECT: **20 drilled samples**

M2020 Surface Mission MUST perform significantly better relative to MSL in order to accomplish mission objectives.

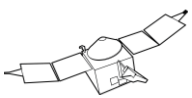
Meeting the Challenge

The Mars 2020 Surface Mission

MARS:

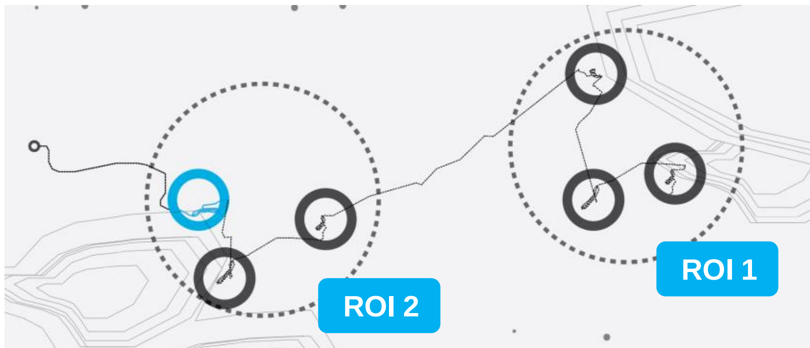


MRO

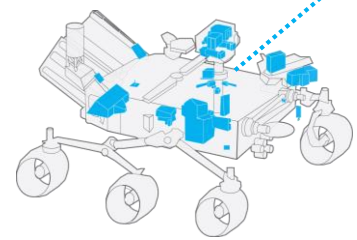


MAVEN

Baseline reference scenario:



Rover & Instruments:



Mastcam-Z
MEDA
MOXIE
PIXL
RIMFAX
SHERLOC
SuperCam

EARTH:

DSN

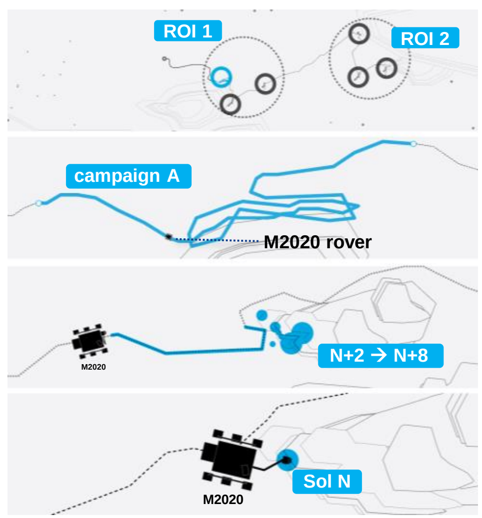
Operations Processes:

STRATEGIC

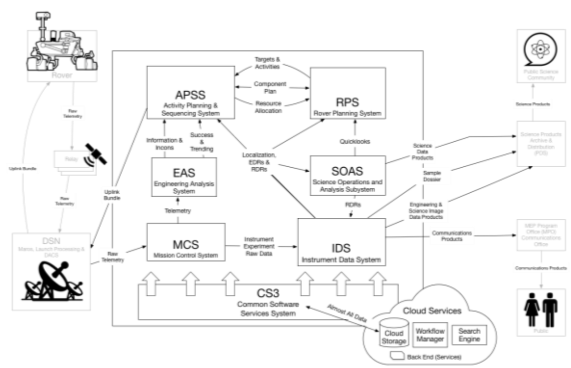
CAMPAIGN PLANNING

CAMPAIGN IMPLEMENTATION

TACTICAL



Ground Software and Hardware:



+ Operations Teams
+ Staffing and Tactical Timeline Performance

Operations Team:

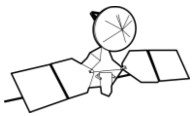
GDS
GDSO
NAV
EO
RO
SO

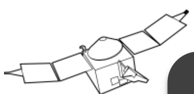
Meeting the Challenge

The Mars 2020 Surface Mission

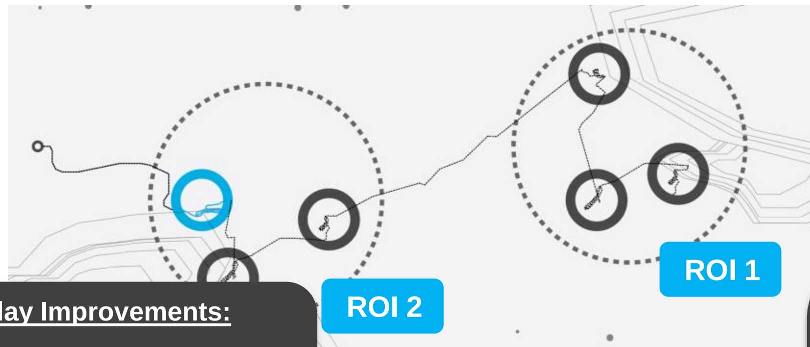
KEY:
Orange text = new / changed since PDR
Blue text = MS PDR completed since PDR

MARS:





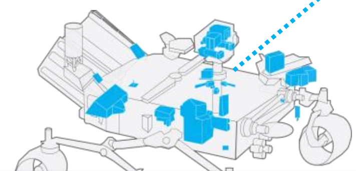
Baseline reference scenario:



KEY Relay Improvements:

- LDPC for all relay orbiters
- MAVEN in suitable relay orbit

Rover & Instruments:



KEY Flight System Improvements:

- 1.5 MY hardware qual lifetime
- Faster Traverse
- Enhanced Nav
- On-Board Simple Planner
- FSW Load and Transition Updates
- Remote Science Productivity
- LDPC Coding for Telecom
- Compression and Data Management
- Proximity Science Productivity

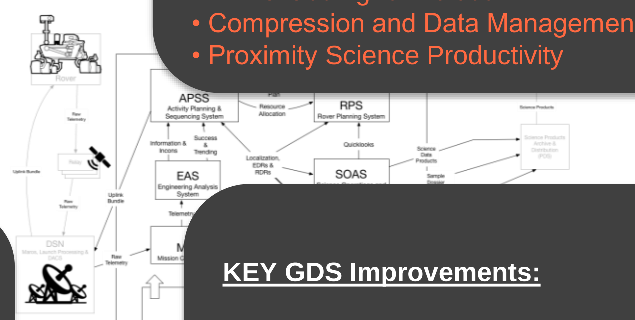
EARTH:

Operations Processes:

KEY Mission Operations Systems Improvements:

- 5 hour tactical timeline
- Science decision making facilitated and moved earlier when possible
- Training focus including additional facilities
- Team structure to elevate key areas (rover planning ops)

Ground S



+ Operatio
+ Staffing
Performa

ons Team:

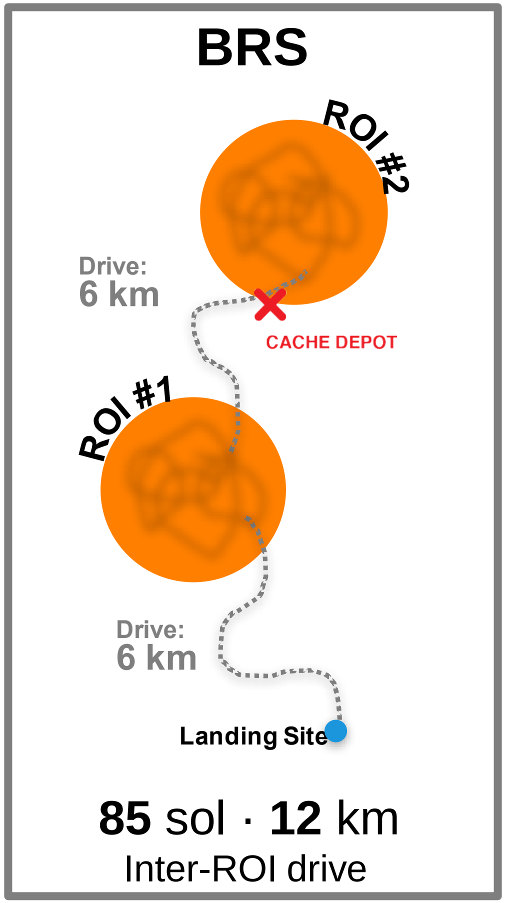
KEY GDS Improvements:

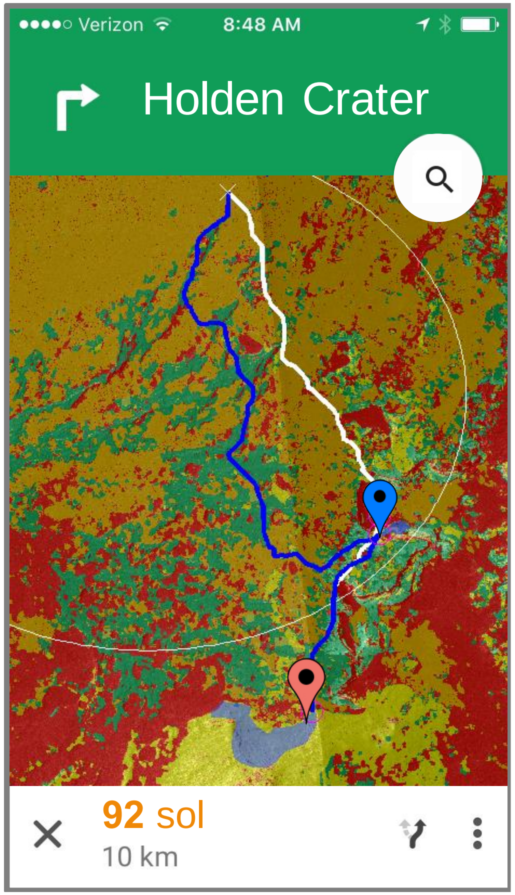
- Planning Unit auto-expansion to uplink products
- Integrated simulation & validation
- Data-to-information quickly
- Science targeting achievability
- Cloud storage and computing usage
- Dashboards and rule-based analysis

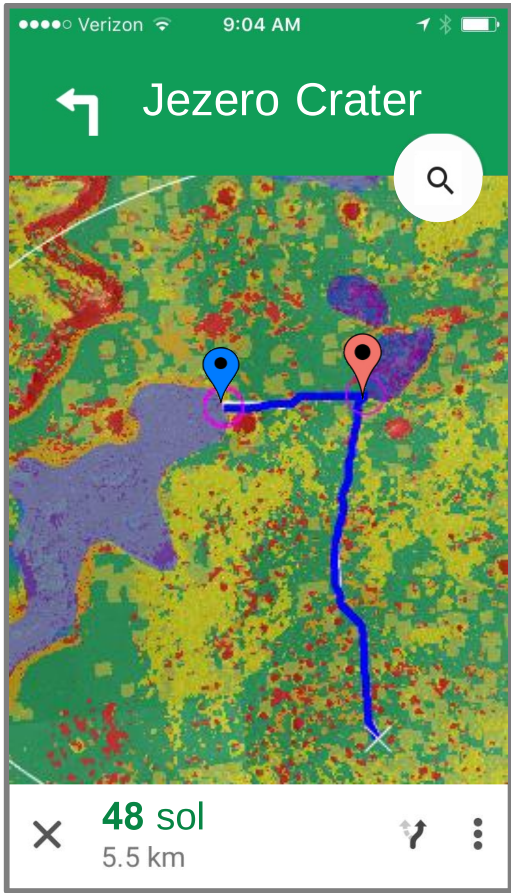
Site Specific Traversability Assessments

Landing Site Specific Analysis

Attempting to move from a generic Baseline Reference Scenario (BRS) to analyzing a specific mission at each landing site



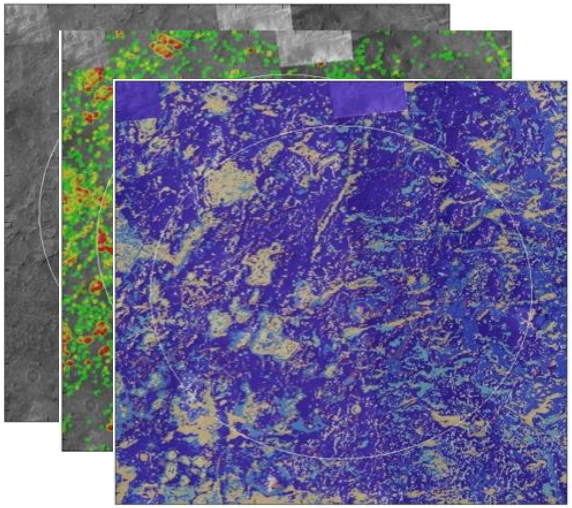




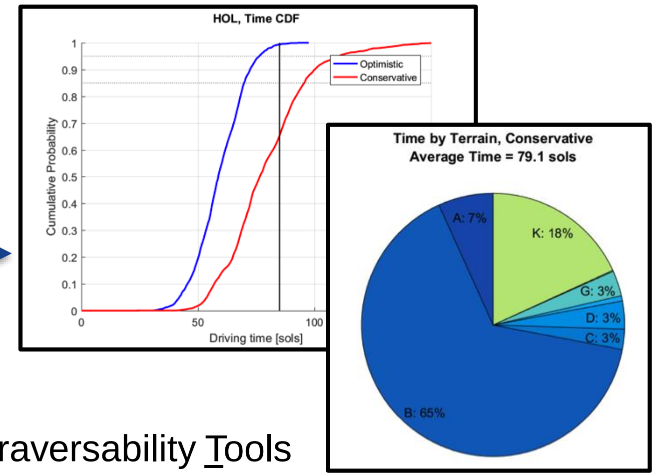
Data-driven Traversability Analysis

Inputs: slope, CFA, terrain type

Output: Statistics of time/distance



MTTT



MTTT = Mars Twenty-twenty Traversability Tools

- Uses slope, CFA, and terrain type to assess traversability (MSL did not use terrain classification)
- Outputs statistical distribution of driving time and distance to visit required ROIs
- Avoids subjectivity by algorithmic evaluation of terrain type and rock abundance
- Solves traveling salesman problem to find the minimum-time path to visit multiple ROIs (MSL had only one ROI)

Monte-Carlo Simulation

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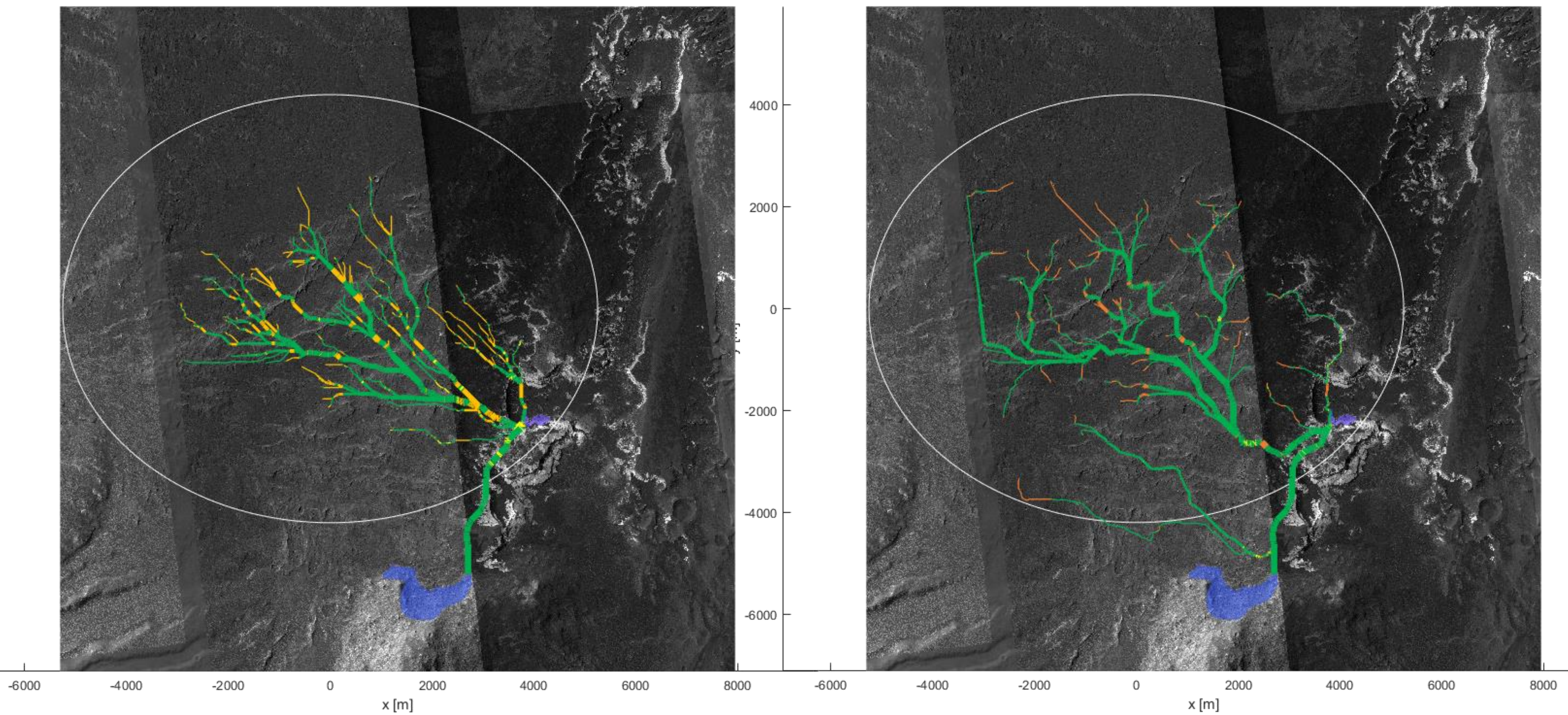
- Monte-Carlo simulation with 8,000 landing points sampled from landing probability distribution
- Many routes converge to the most traversable terrains, forming natural "highways"

Optimistic **Conservative**



Optimistic legend: 65 m/hr, 53 m/hr, 48 m/hr, 41 m/hr, 11 m/hr

Conservative legend: 65 m/hr, 53 m/hr, 24 m/hr, 11 m/hr

Summary of Status & Results

	90% Time [Sol]	90% Distance [km]	Traversability challenges
BRS	85	12	(Baseline reference scenario)
CLH	57.7 – 72.7	8.3 – 9.3	Go-to site
EBW	28.9 – 47.6	3.8 – 4.6	Mantling unit with ripples Scarps on delta
HOL	73.7 - 106.8	10.6 – 12.5	Go-to site; >60% covered by potentially no-Autonav ripples; highways exist but in unfavorable directions Access to ROI (layered deposit) challenging due to high slope/sand
JEZ	35.5 – 38.1	5.5 – 5.8	High CFA on SE of ellipse but ROIs are on NW
MAW	19.1 – 28.0	2.7 – 3.2	Surface roughness could limit the speed of Autonav, but can achieve mission with conservative estimate
NES	15.1 – 16.5	2.3 – 2.4	Buttes and sand deposits, but localized and easy to go around
NIL	66.7 – 86.7	9.9 – 10.6	Go-to site Ripples but mitigated by highway in the favorable direction
SWM	29.6 – 52.5	3.7 - 4.0	Scarps, but traversable routes seem to exist across

Acknowledgements

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Mars 2020 Project

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Site Proposers

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- Melissa Rice (EBW)
- Sanjeev Gupta (EBW)
- Nick Warner (EBW)
- Ross Irwin (HOL)
- James Wray (HOL)
- John Grant (HOL)
- Jack Mustard (JEZ, NES, NIL)
- Bethany Ehlmann (JEZ, NES)
- Tim Goudge (JEZ)
- Briony Horgan (MAW)
- Damien Loizeau (MAW)
- Francois Poulet (MAW)
- Michael Bramble (NES)
- Kevin Cannon (NIL)
- Becky Williams (SWM)

Site Specific Surface Mission Performance Assessment

How do we model the surface mission?

- We have developed an advanced suite of tools/models that can help us to **evaluate and measure key mission performance metrics** such as:
  - Mission duration needed to accomplish surface mission objectives
  - Ops Efficiency needed to accomplish surface mission objectives
  - Data volume generated during surface mission
  - Drive routes and terrain characteristics for landing sites
  - Amount of science investigation conducted
    - number of sols, number of observation types, number of locales investigated, number of samples collected, data volume generated, …

- Some of the tools/models implemented:
  - MTTT (Mars Twenty-Twenty Traversability) *new for M2020*
    - Drive route planning and terrain classification
  - MSLICE for Mars 2020 *modified from MSL*
    - Planning tool used to build and model sol scenarios
  - Operations Efficiency Analysis *new for M2020*
    - Uplink plan process scheduling tool
  - TOAST orbiter relay simulation
    - Relay telecom simulator for rover-to-orbiter data links
  - Surface Mission Performance model *new for M2020*
    - Monte-carlo of various mission characteristics to understand overall performance

(1) Landing Site Mobility Characteristics

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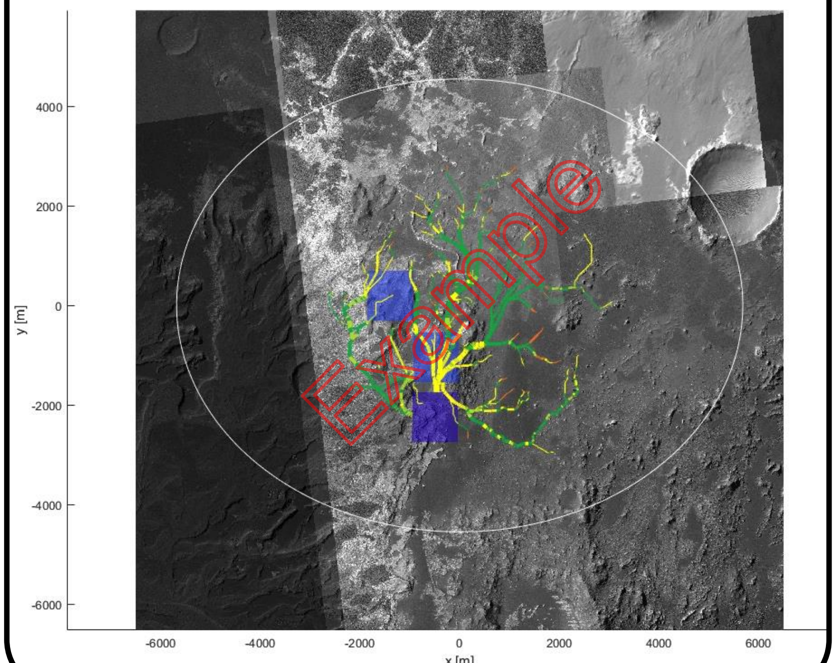
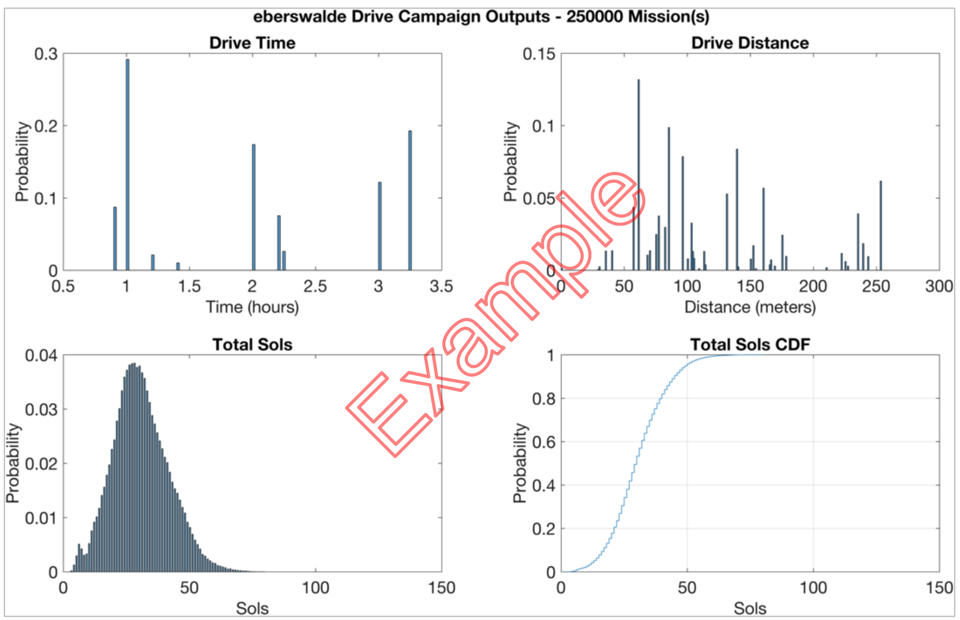
MTTT



Mission Performance Model

- Drive Path Distances
- Terrain Classifications
- Drive Modes & Rates
- Drive Sol Types
- Landing Site Environments



(2) Landing Site Science Exploration

- Science exploration objectives and approach can vary from site-to-site.
- The Mars 2020 Project has collaborated with site proposers to define and prioritize potential **Regions-of-Interest** (ROI) for detailed science exploration within each landing site.
- ROI locations also provide mobility path planning destinations, which gives overall traverse distance characteristics for each site

(2) Landing Site Exploration Summary

ROI #2

	Campaigns	Units	Samples	ROI Drive Distance	Walkabout Drive Dist.
Eberswalde	3	3	7	200	500
Columbia Hills	1	2	5	100	500
Holden	2	4	6	1000	500
Jezero	2	2	3	200	500
Mawrth	1	2	4	500	500
NE Syrtis	2	4	6	200	500
Nili	2	6	6	500	500
SW Melas	2	4	6	100	500
BRS	2	5	7	500	500

ROI #1

	Campaigns	Units	Samples	ROI Drive Distance	Walkabout Drive Dist.
Eberswalde	3	3	7	200	500
Columbia Hills	2	6	8	100	500
Holden	2	6	8	100	500
Jezero	2	10	10	500	500
Mawrth	3	6	9	300	500
NE Syrtis	2	4	6	200	500
Nili	2	4	6	500	500
SW Melas	2	6	8	500	500
BRS	2	5	7	500	500

Waypoint(s)

	Rock Sample	Regolith Sample
Eberswalde	1	1
Columbia Hills	2	1
Holden	2	0
Jezero	2	1
Mawrth	2	1
NE Syrtis	3	1
Nili	3	1
SW Melas	2	0
BRS	1	1

Site-Specific ROI & Waypoint Scenario Totals

	Total Campaigns	Total Units	ROI Samples	Waypoint Samples	Witness Samples	Total Samples	Total ROI Distance (m)
Eberswalde	6	6	14	2	4	20	3800
Columbia Hills	3	8	13	3	4	20	1600
Holden	4	10	14	2	4	20	3100
Jezero	4	12	13	3	4	20	2700
Mawrth	4	8	13	3	4	20	2600
NE Syrtis	4	8	12	4	4	20	2400
Nili	4	10	12	4	4	20	3000
SW Melas	4	10	14	2	4	20	2600
BRS	4	10	14	2	4	20	3000

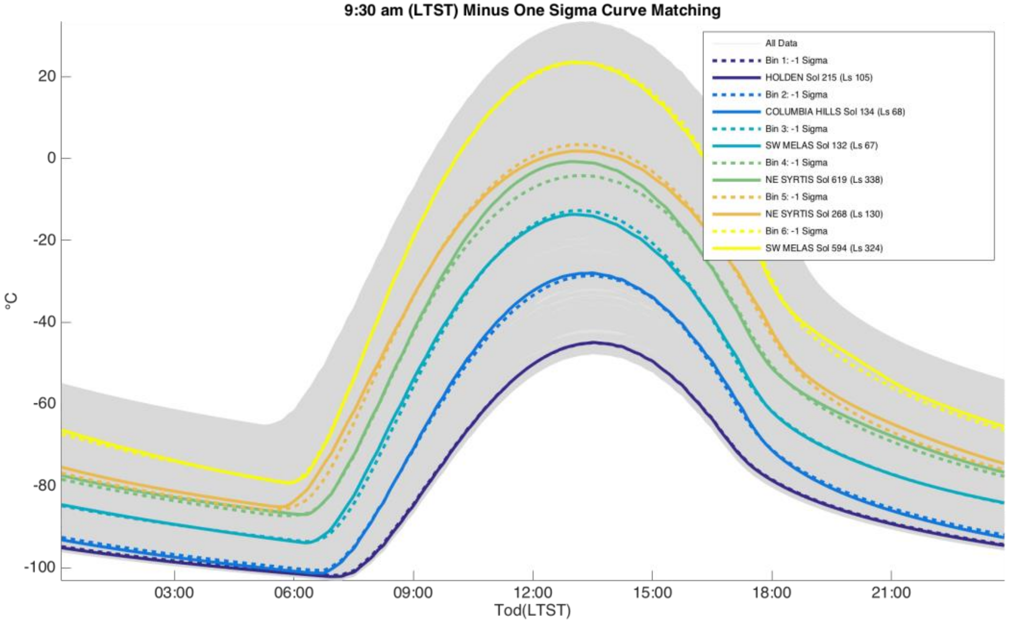
(3) Landing Site Environments

[top-right]
6 diurnal environments (aka ”Bins”) derived from all landing site annual environments.

[bottom-right]
Percentage of environment bin usage for each landing site assuming 1.25 Mars year surface mission.

Thermal analysis on Environment Bins provides estimates for survival heating, mechanism heat-to-use, instrument warm-up and ops time-of-day constraints used in Sol Type scenarios.

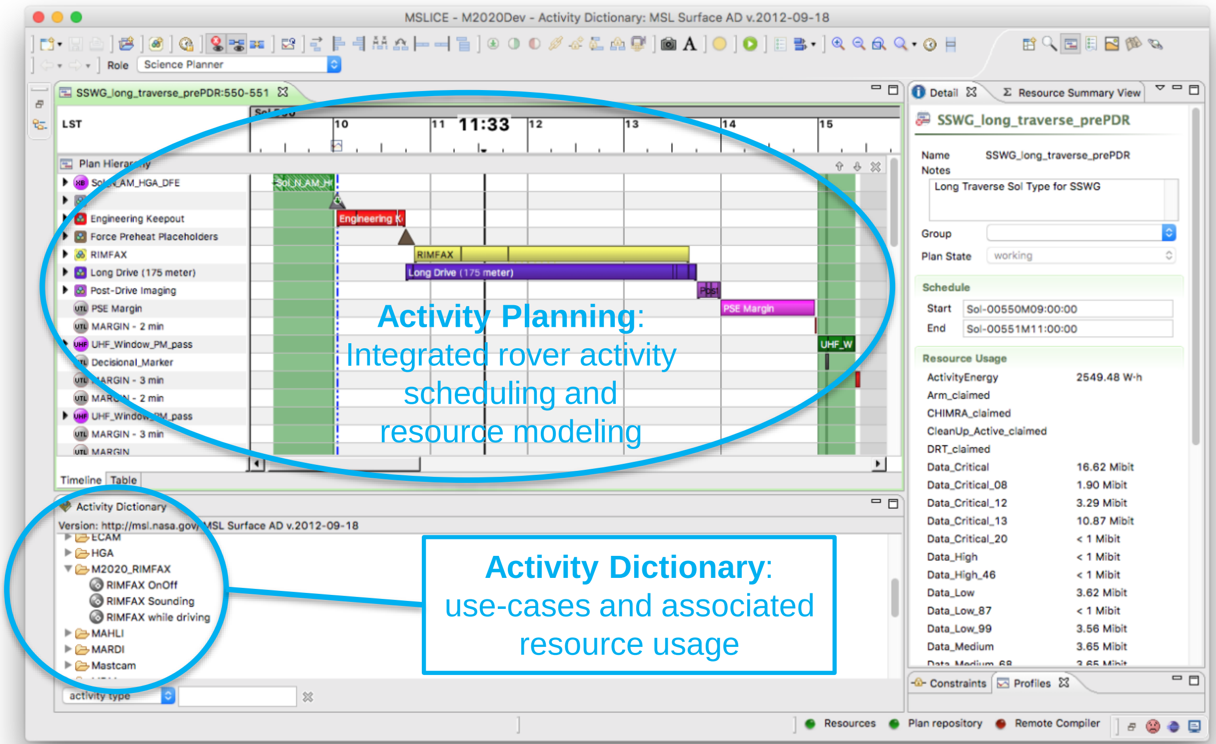
9:30 am (LTST) Minus One Sigma Curve Matching



	(coldest)	1.25 MY Environment Bin %				(warmes)
	1	2	3	4	5	6
Columbia Hills	0%	37%	16%	10%	14%	24%
Eberswalde	26%	21%	10%	7%	10%	26%
Holden	34%	17%	9%	7%	9%	25%
Jezero	0%	0%	22%	65%	12%	0%
Mawrth	0%	10%	15%	41%	34%	0%
NE Syrtis	0%	0%	16%	66%	18%	0%
Nili	0%	0%	18%	60%	22%	0%
SW Melas	0%	26%	23%	11%	17%	22%
BRS	0%	0%	100%	0%	0%	0%

(4) Sol Type Scenarios

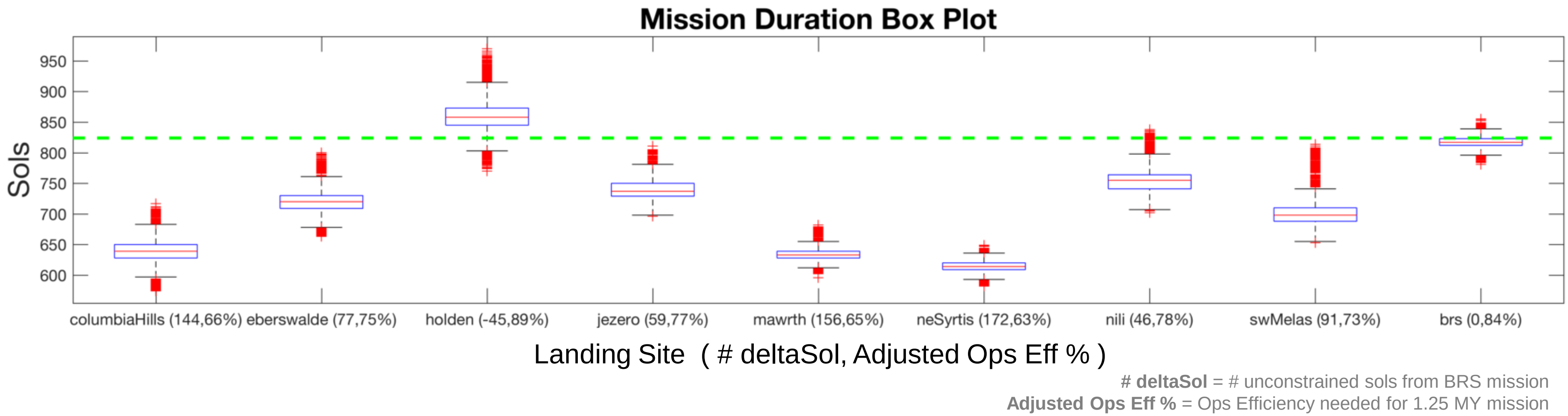
- Mission scenario modeling employs MSLICE planning tool
  - Inherited from MSL operations and adapted for M2020 Mission Planning.
  - Provides ops-like sol scenario planning and resource/constraint management
  - High-fidelity resource modeling (time/duration, power/energy, data volume)



(4) Sol Type Scenario Summary

Sol Types	Description	Sol Type Duration (# sols)					
		Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6
Remote Sensing Sol Types							
Survey Remote Sensing	Detailed remote sensing of new location, used to inform sol path planning	1	1	1	1	1	1
Workspace Remote Sensing	Detailed remote sensing of Robotic Arm workspace	1	1	1	1	1	1
Robotic Arm Sol Types							
Natural Proximity Science	Investigate [2] surface targets.	2	1	1	1	1	1
Abraded Proximity Science	Abrade surface target and detailed investigation	3	2	2	2	2	2
Sample Coring & Borehole Science	Acquire rock/regolith sample and investigate borehole	4	4	3	3	3	3
Mobility Sol Types		**(drive times vary, all are 1 sol duration)**					
Long Drive	Blind+Autonav drive modes. Optimized for longest possible drive.	1	2	2.2	3	3	3.25
Medium Drive	Blind+Autonav drive modes with ~1 hour limited remote sensing	1	1.2	1.4	2	2	2.5
Short Drive	Blind-only drive mode, limited to ~30 meters. Remaining resources for remote sensing	0.9	0.9	0.9	1	1	1
Precision Approach	10-meter approach to proximity science "Parking Spot". RSM workspace imaging only.	1	1	1	1	1	1
Precision Approach with Go & Hover	10-meter approach to proximity science "Parking Spot" AND deploy arm for WATSON imaging of workspace,	n/a	n/a	1	1	1	1
Multi-sol Drive	Autonav drive mode without ground-in-the-loop. Scheduled on Constrained sol only.	1	2	2.2	3	3	3.25
Constrained Sol Types							
ISRU	MOXIE full O2 production cycle	1	1	1	1	1	1
MEDA-dedicated	MEDA intensitve observation mode. Can be scheduled on a Constrained Sol	1	1	1	1	1	1

Mission Performance Modeling Results



- Results of Mission Performance monte-carlo modeling shown above.
- Conclusions
  - Project-level requirements and design support the BRS mission
  - 7-of-8 landing sites perform within the BRS mission capability. The exception is Holden Crater.
    - Combination of Holden environment and go-to ROI locations cause it to exceed BRS mission at the 14th percentile mission duration.

Engineering Summary

Engineering Summary

Site	EDL	Surface	Comments
Columbia Hills	Green	Green	
Eberswalde	Green	Green	
Holden	Green	Yellow	Likely to exceed the prime mission duration to accomplish science objectives
Jezero	Green	Green	
Mawrth	Green	Green	
NE Syrtis	Green	Green	
Nili Fossae	Green	Green	
SW Melas	Yellow	Green	Lack of confidence in atmosphere modeling results coupled with significant terrain hazards bordering the landing ellipse raise concerns

All candidate landing sites are viable; however, have some engineering concerns with Holden and SW Melas