Mars 2040 Optimization: Assignment 1, Section B

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1 Project Proposal

1.1 Project Introduction

Our team has decided to do optimization on the Mars 2040 project that Eric worked on in Spring 2015 as the SDM term project. This project generated a model of a Mars outpost architecture including the Transportation Logistics, Surface Habitation, ISRU and Exploration aspects. The model was run through a Tradespace exploration to identify architectures that minimized the IMLEO (initial mass to low-earth orbit, i.e. the total payload launched from the Earth surface each synodic period) while attempting to maximize the Ścientific Valueás defined as the crew-hours per synodic period available for exploration and research, multiplied by a rank scoring of the landing sites based on an independant study performed early on in the term.

We only have one modification to the model currently planned; to make a small improvement on the utility metric for this project. Instead of using the more subjective site scoring from the SDM term project, we will formalize the utility as suggested by Ward et. al.[1] to consider quantitative scientific value.

Since the tradespace exploration has already been performed, we will focus this project on more in depth aspects. We will re-run the tradespace exploration with the improved utility metric on the same design space as setup by the SDM term project. From that point, we will select and baseline the architectures in the fuzzy pareto-optimal region, as defined by Smaling and deWeck[2]. This should give us approximately 300 baseline architectures. as the starting point for our optimization.

The first portion of our optimization will focus on technology road-mapping. We will convert some of the parameters in existing model into design variables, based on the possibilities for technological development. For example, we might take the $LOX/LH_2 I_{sp}$ from a parameterized 448 [seconds] and turn it into a variable across the range of $(448, 480)$ that we could correlate with a development cost estimate for the improvement in I_{sp}. Once we do this for multiple technologies, we can run an optimization of development spending across the portfolio of technologies for the baselined architectures and determine where the money would be best spent in order to improve the future exploration campaign.

If the first portion goes well, and time permits, we would also like to investigate the build-up campaign as well. With a baselined technology capability roadmap, we could run through the 300 candidate architectures from a null-infrastructure to the full 20 person outpost, looking for a sub-game perfect campaign that would optimize not only the steady-state re-supply missions, but the entire campaign from the beginning.

1.2 Formal Problem Statement

To optimize the improvements to a campaign to setup a permanently inhabited outpost on the surface of Mars from a technology development budget, **by** altering the design variables associated with technological performance across pre-selected architectures, **using** systems design optimization methodologies.

1.3 Design Variables, Parameters, Constraints, Bounds and Objectives

Objective Function

$$\text{minimize } J(\mathbf{x}) = \begin{bmatrix} \text{Campaign Utility} \\ \text{Resupply Cost} \\ \text{Technology Development Cost} \end{bmatrix}$$

Design Variables

$$\mathbf{x} = \begin{bmatrix} Isp_{LH_2} \\ Isp_{NTR} \\ \epsilon_{ISRU} \\ \alpha \\ C_{surf} \\ C_{transit} \end{bmatrix} = \begin{bmatrix} \text{LH}_2 \text{ Isp} \\ \text{Nuclear Thermal Rocket Isp} \\ \text{ISRU efficiency} \\ \text{Architecture} \\ \text{Surface Crew Size} \\ \text{Transit Crew Size} \end{bmatrix}$$

Parameters

Most of the architecture selection variables from the SDM term project model have been effectively parameterized. The architectural variables are no longer independently enumerated, instead, the have been conglomerated into a single design variable of α which selects a single complete architecture from the pre-selected pool of architectures in the fuzzy pareto-optimal region of the initial tradespace study.

See the Master Table in the Appendix for the complete list of parameters.

Constraints

$$frac3 * C_{crew} C_{surf} \geq 1 \tag{1}$$

Bounds

$$Isp_{LH_2} = [430, 480]$$

Typical Isp, to a little more than the highest recorded

$$Isp_{NTR} = [800, 1500]$$

Isp recorded under development in the 1960's, to the theoretical maximum

$$\alpha = \{\text{Fuzzy Pareto-Optimal Architectures}\}$$

	Earth Entry	Descent	Ascent	Return Transit	Transit Habitat	Outgoing Transit	Lunar ISRU	Mars ISRU	ISFR and Sparing	Astronaut Time	Surface Power	Surface Habitat	ECLSS	Staging	Site Selection
Earth Entry															
Descent								142	36, 37, 38, 39				255, 257, 262		125
Ascent	165, 166			167											
Return Transit	165, 166				162, 160, 158										
Transit Habitat															
Outgoing Transit		53													
Lunar ISRU						62									
Mars ISRU			186, 187	171, 172, 173									255		125
ISFR and Sparing								140			27	221	259		
Astronaut Time															
Surface Power												223	260		125
Surface Habitat								142							
ECLSS												221, 222			
Staging		53				62	69								
Site Selection															
		LEGEND:	Feed Forward		Feed Back		# corresponds to master table entry								

Figure 1: Initial Un-ordered DSM matrix for Model modules

2 N^2 Diagram

Figure 1 shows the first pass at the DSM for the modules of our model, which contains a lot of feedback I/O on the top of the matrix. The modules were re-ordered, as shown in figure 2, and all of the I/O was able to be moved to the bottom of the diagonal. As such, we will not have any iterative loops between modules.

3 Block Diagram

Figure 3 shows the model layout from the Mars 2040 SDM term project from the Spring term of 2015. This will be the starting point for our model for MSDO. Throughout the semester, the model may require some modifications based on the changes in scope (going from a tradespace exploration to a development optimization.) However, we feel like this arrangement does a good job setting up the project, and the changes will not likely require massive rearrangements.

	Transit Habitat	Earth Entry	Return Transit	Ascent	Surface Habitat	ECLSS	Site Selection	Mars ISRU	Surface Power	ISFR and Sparing	Astronaut Time	Descent	Outgoing Transit	Lunar ISRU	Staging
Transit Habitat															
Earth Entry															
Return Transit	162, 160, 158	165, 166													
Ascent		165, 166	167												
Surface Habitat															
ECLSS					221, 222										
Site Selection															
Mars ISRU			171, 172, 173	186, 187		255	125								
Surface Power					223	260	125	142							
ISFR and Sparing					221	259		140	27						
Astronaut Time															
Descent						255, 257, 262	125	143		36, 37, 38, 39					
Outgoing Transit												53			
Lunar ISRU													62		
Staging												53	62	69	
		LEGEND:	Feed Forward		Feed Back		# corresponds to master table entry								

Figure 2: Ordered DSM matrix for Model modules

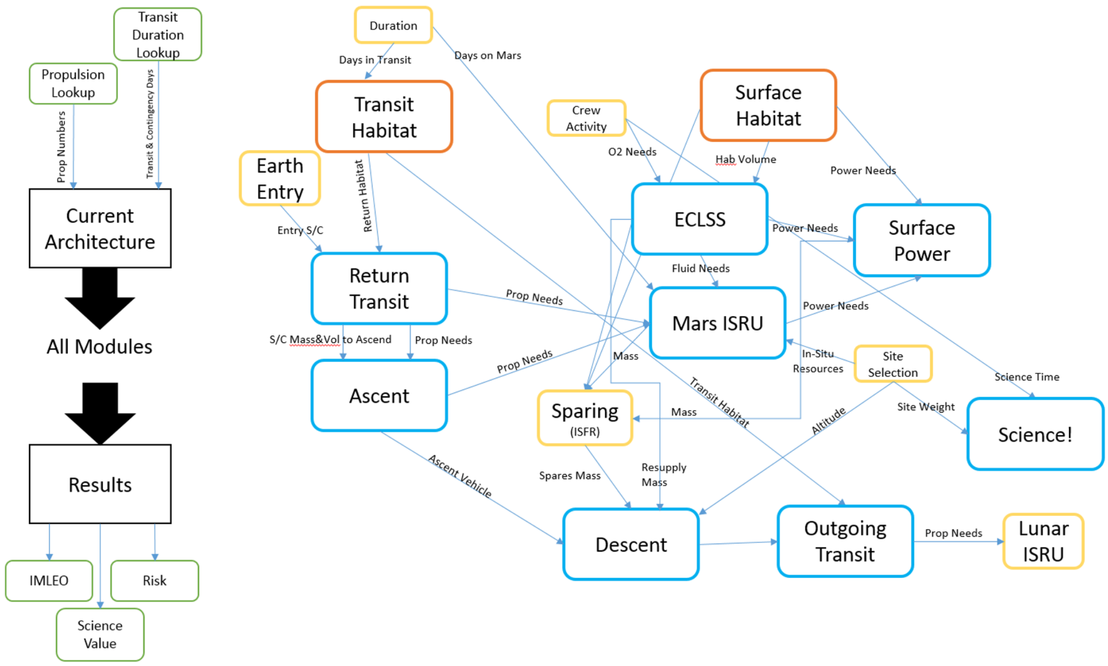

Figure 3: Block Diagram of Model from the Mars2040 Project Spring 2015

References

[1] Eric D. Ward, Ryan R. Webb, Olivier L. deWeck, *A Method to Evaluate Architectural Comparisons for a Campaign to Explore the Surface of Mars*. Manuscript submitted for publication, Acta Astronautica. 2016.

[2] Smaling R., de Weck O., "Assessing Risks and Opportunities of Technology Infusion in System Design", *Systems Engineering*, 10 (1), 1-25, Spring 2007

A Master Table

Name	Value	Unit
thisvar	10	seconds