Enabling Space Exploration Medical System Development Using a Tool Ecosystem

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Agenda

- Background Information
- Problem Introduction and Proposed Solution
- Tool Suite Overview
- Tool Suite Pilot Projects Overview
- Significance and Limitations of Work
- Future Work

Background Information

The Human Research Program (*HRP*):

- NASA program that provides human health and performance countermeasures, knowledge, technologies, and tools
- Enables safe, reliable, and productive human space exploration

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Five Elements of HRP:

- Human Factors & Behavioral Performance
- Exploration Medical Capabilities (*ExMC*)
- Human Health Countermeasures
- Research Operations and Integration
- Space Radiation

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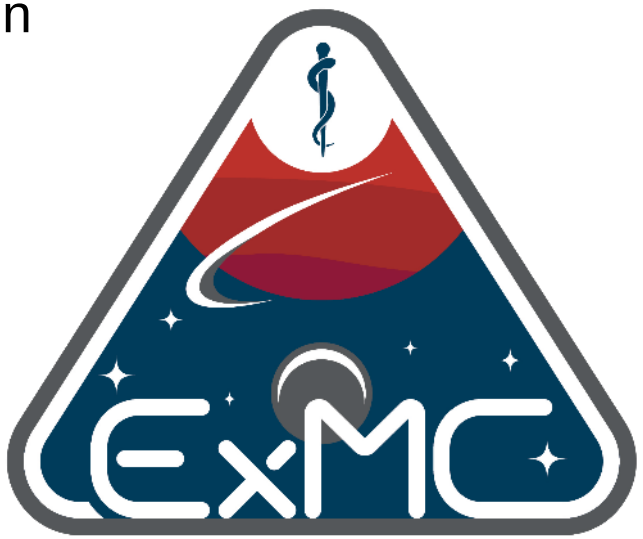
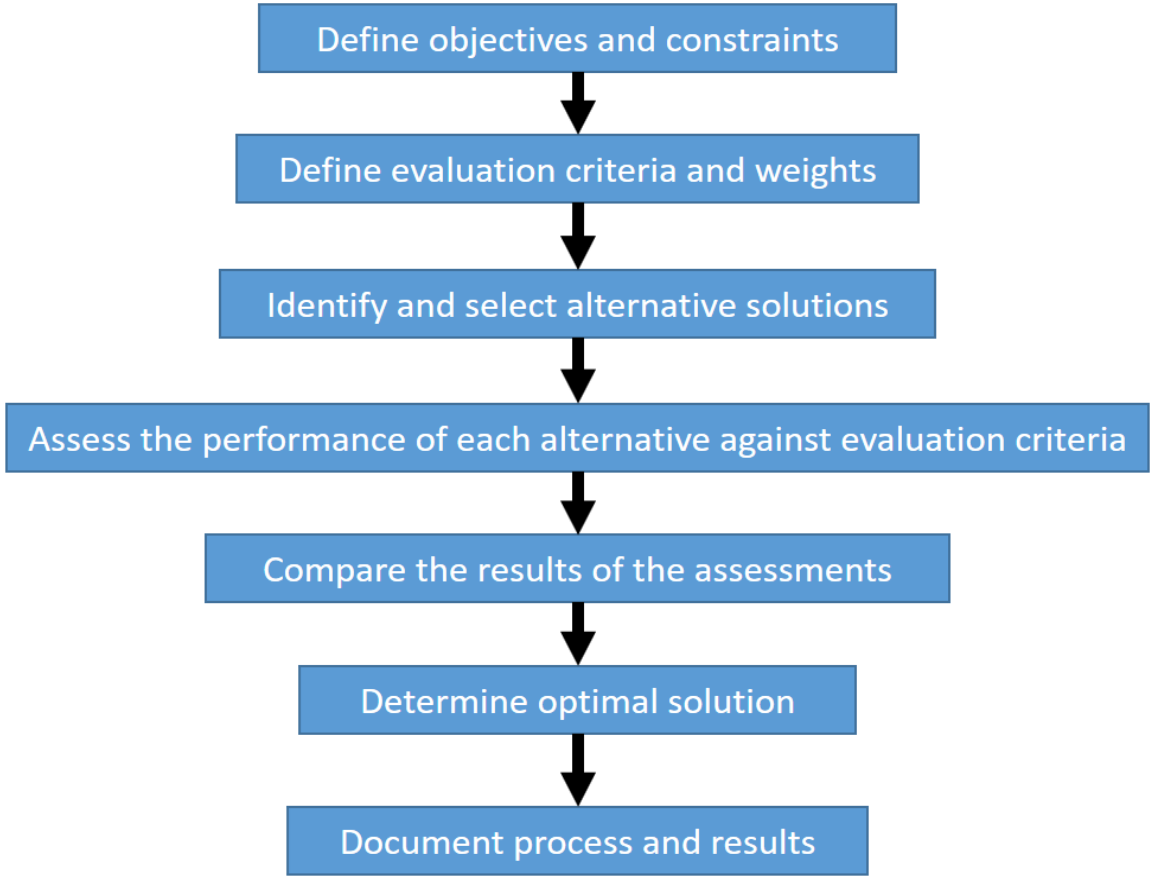


Exploration Medical Capability

Trade Study Overview

A trade study is a quantitative decision making activity used to identify the most acceptable solution amongst a set of proposed solutions.



Trade Study Overview

A trade study is a quantitative decision making activity used to identify the most acceptable solution amongst a set of proposed solutions.

What type of car should I buy?

How does a 10% reduction of mass and volume affect the capabilities of medical imaging?

Where should I go out to dinner?

What neighborhood should I move to?

How many suitcases should I bring on my vacation?

Problem Introduction

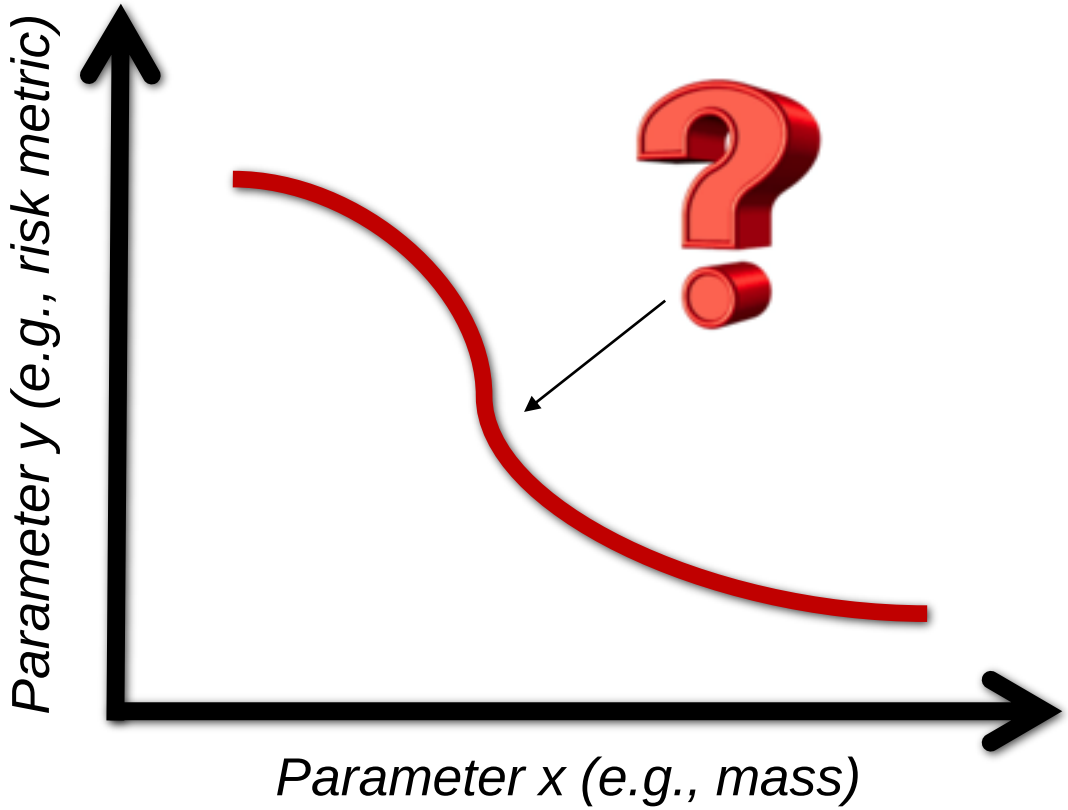
NASA is committed to successfully extending human exploration beyond Low Earth Orbit.

Deep space will be different…

Problem Introduction

NASA ExMC's Need:

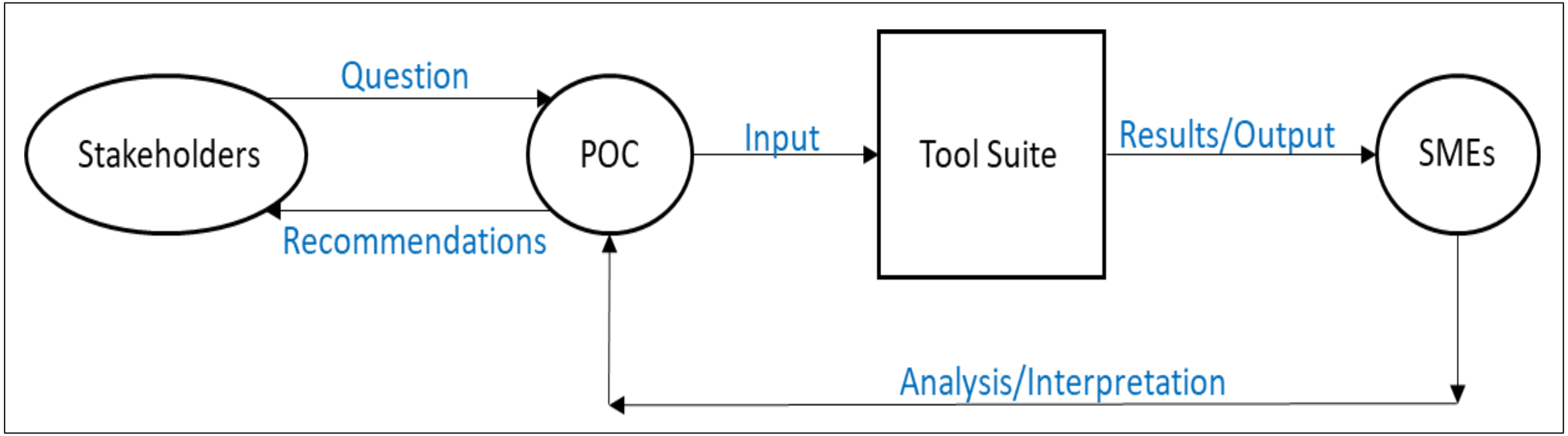
Provide a *data-driven* means to inform human health and performance *risk mitigation* interests during *resource constrained* exploration mission development.



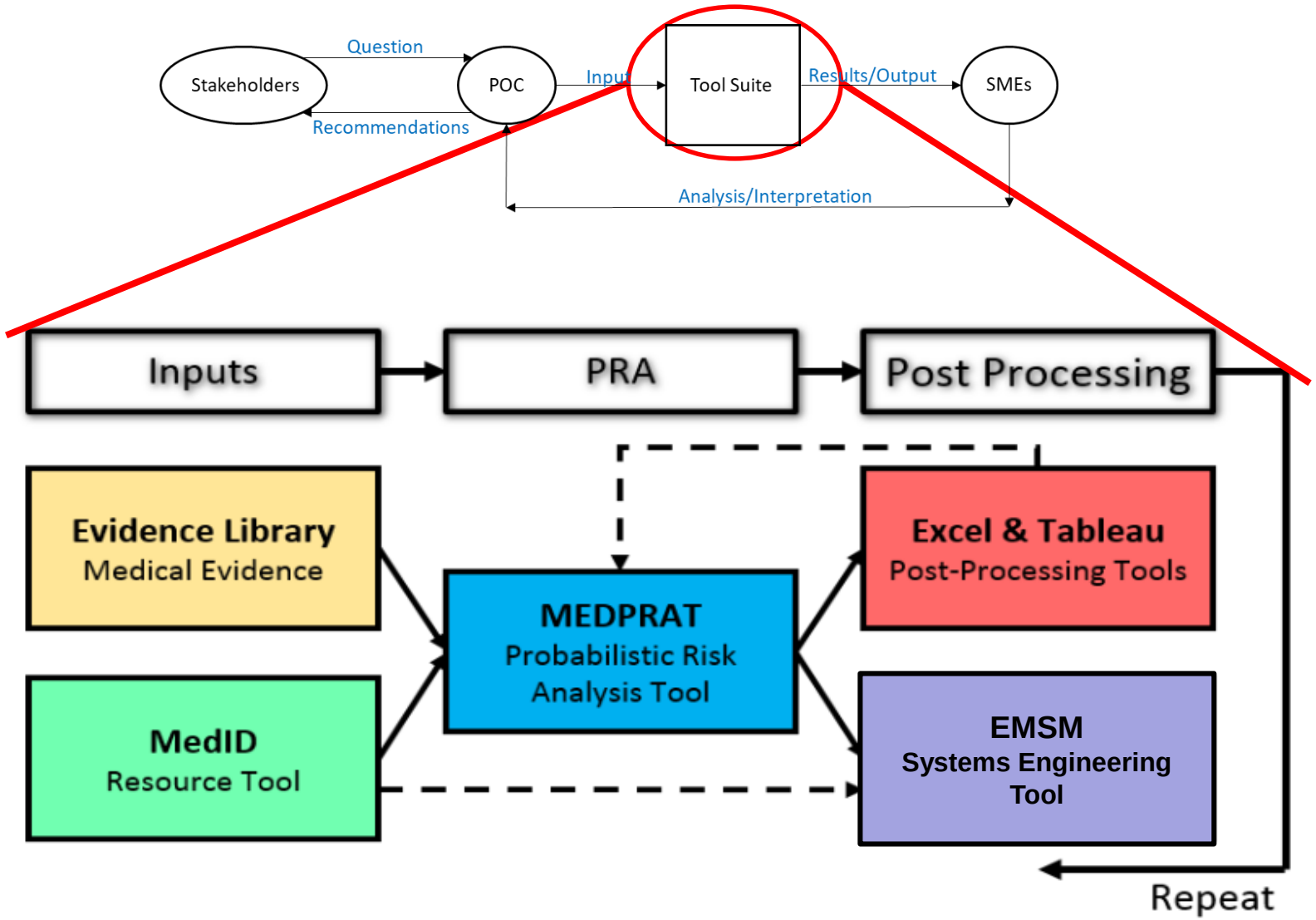
Proposed Solution

To facilitate the exploration beyond Low Earth Orbit with constrained resources, NASA's ExMC Element is:

- Utilizing a *Model-Based Systems Engineering* approach
- Building a tool suite ecosystem to perform *trade study analyses*

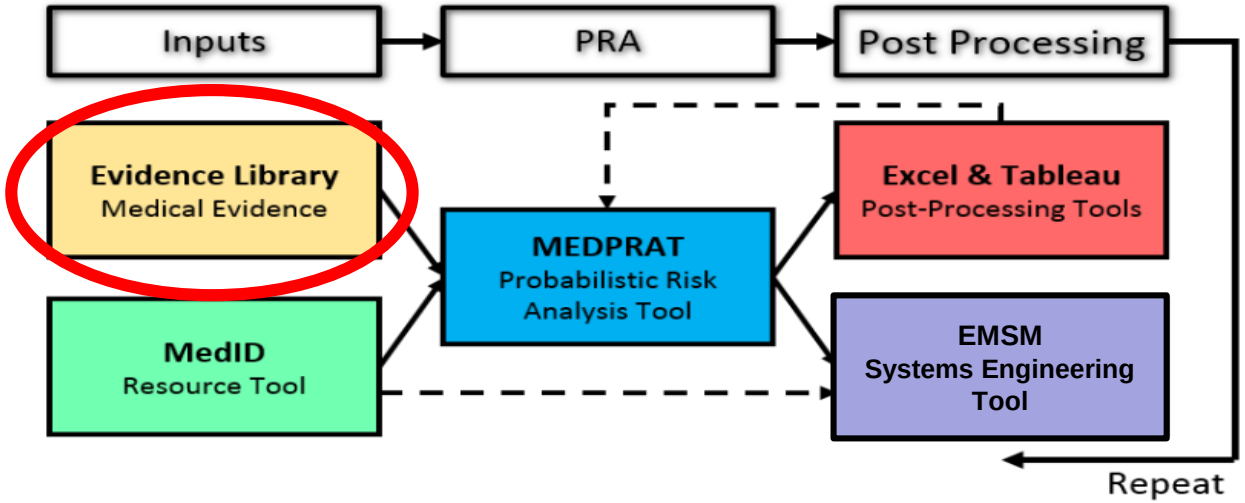


Tool Suite Overview



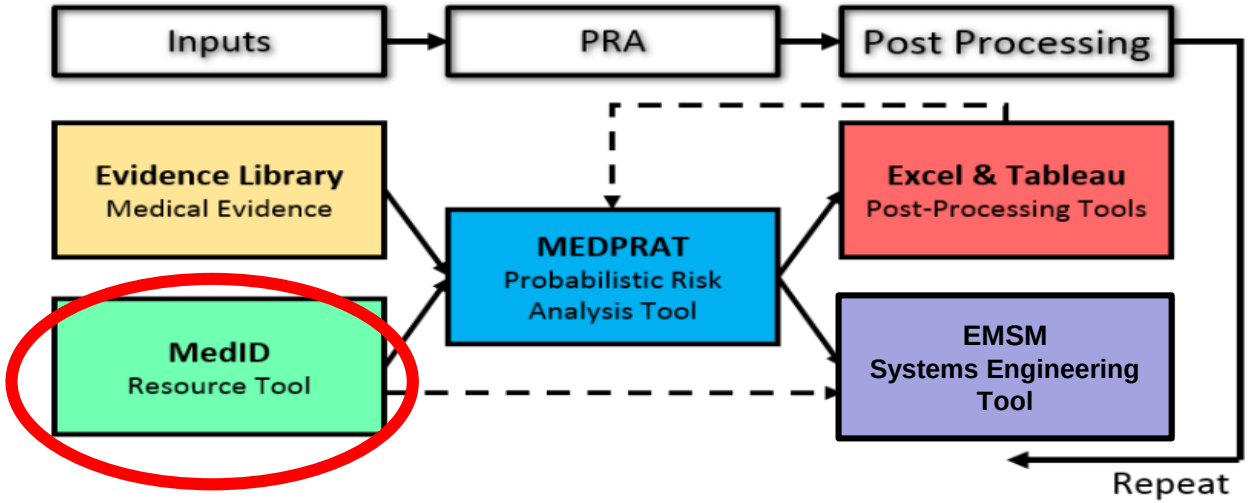
Tool Suite Description – Evidence Library

Evidence Library	– Condition incidence rates – Clinical phase durations (how long a condition treatment lasts) – Likelihoods of mortality or need to return to definitive care – Functional impairment



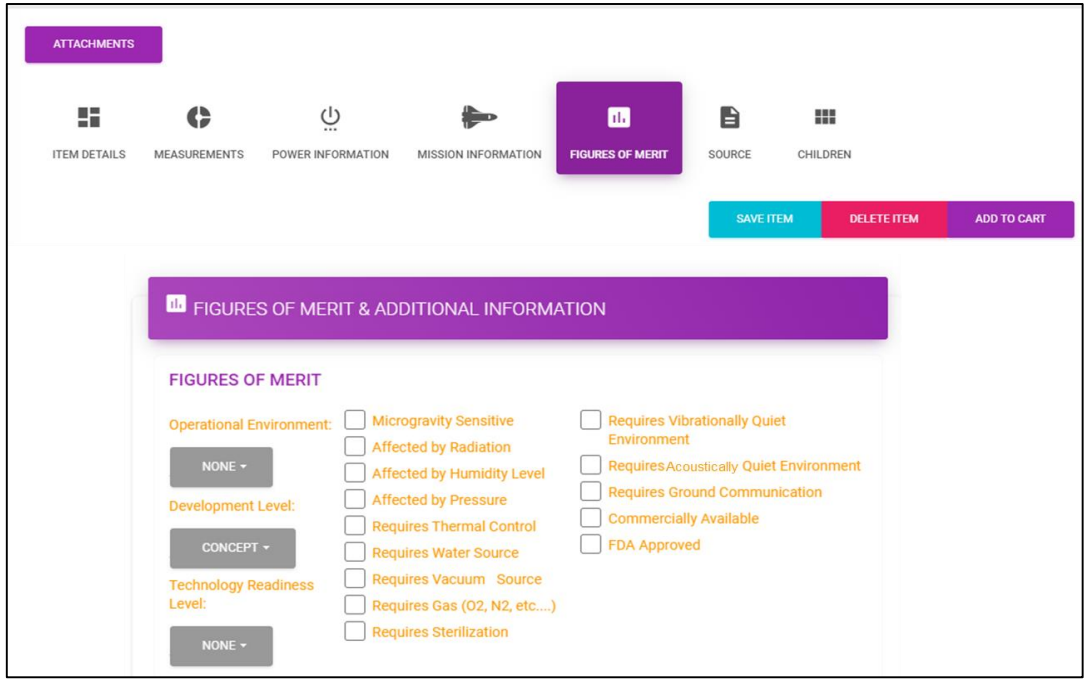
Tool Suite Description – MedID

Medical Item Database (MedID)	Secure, cloud-based database of medical items and resources potentially available for spaceflight



Tool Suite Description – MedID

Selected capabilities of MedID:



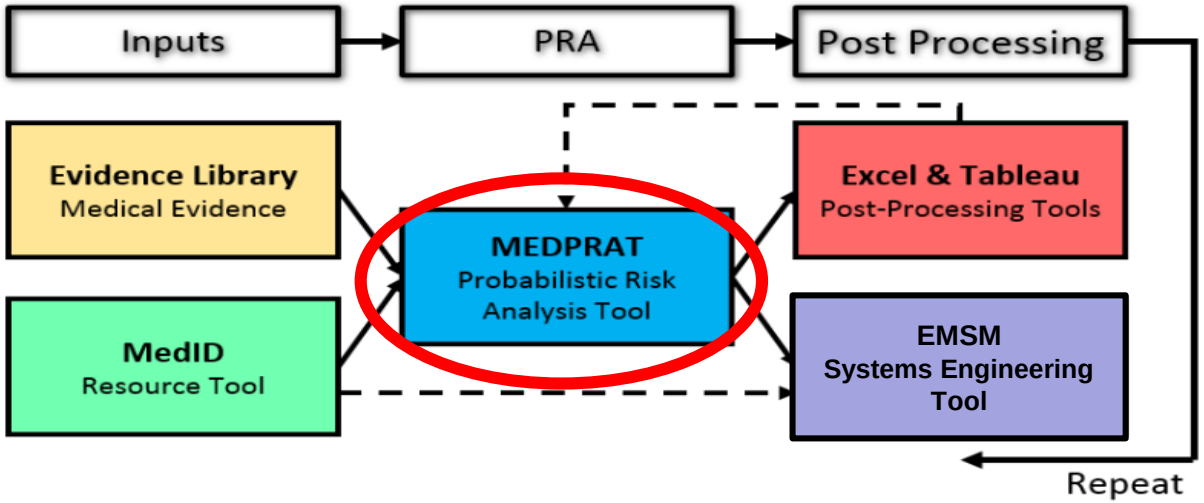
Figures of Merit: Shows the ability to characterize and sort resources based on physical characteristics

Medical System Master Equipm	Date Created				TOTALS:		Total Mass:	Total Volume	Total Power:
Trial Run: 38_TI	8/15/2019						kg	cm^3	watt
							4.8753181	15708.768	400
Resource	Initial_Quantity	Consumable	Essential	Mass	Volume	Power	Total_Mass	Total_Volume	Total_Power
				kg	cm^3	watt	kg	cm^3	watt
ABILIFY (ARIPIPRAZOLE) 5 MG	0	1	1	0.00013	0.1	0	0	0	0
ABILIFY (ARIPIPRAZOLE) 7.5 MG/	0	1	1	0.00024	0.2	0	0	0	0
ABSORBABLE SUTURE 3.0	1	1	1	0.0567	46.9	0	0.0567	46.9	0
ACE BANDAGE 2 INCHES	1	0	1	0.02268	31.7	0	0.02268	31.7	0
ACE BANDAGE 3 INCHES	1	0	1	0.03118	42.6	0	0.03118	42.6	0
ACE BANDAGE 4 INCHES	1	0	1	0.04536	51.6	0	0.04536	51.6	0
ADRENALINE (EPINEPHRINE 1:10	1	1	1	0.01	10	0	0.01	10	0

Master Equipment List: Shows an example snapshot of a list of some resources available and their quantities, mass, volume, and power

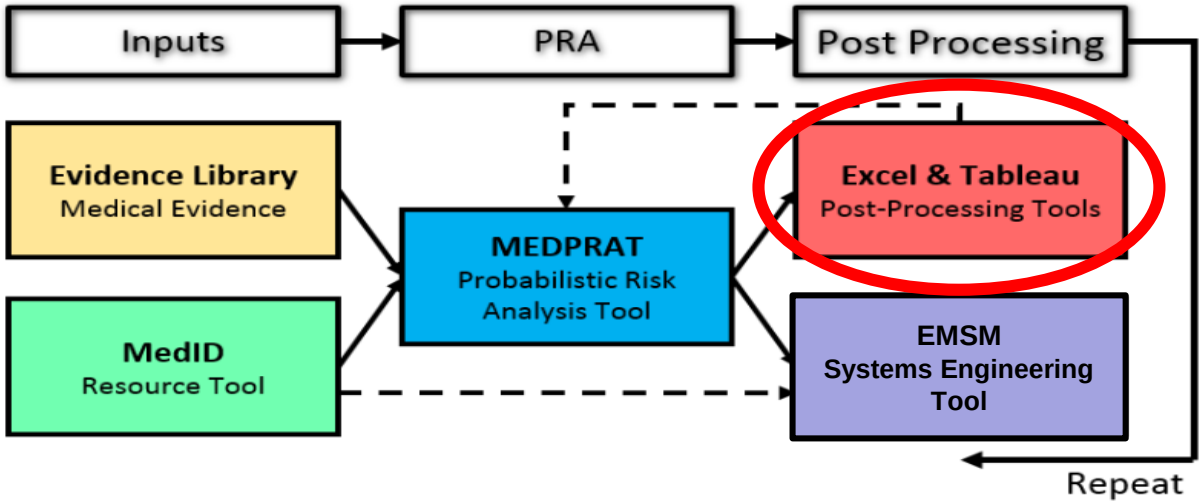
Tool Suite Description – MEDPRAT

Medical Extensible Dynamic Probabilistic Risk Assessment Tool (MEDPRAT)	– Determines the most nearly optimal set of medical resources to meet target values within acceptable risk thresholds – Computes risk factors, condition occurrences, and resource utilization for a given mission and crew



Tool Suite Description – Excel & Tableau

Excel & Tableau	Visualizes pertinent MEDPRAT data in the context of user queries

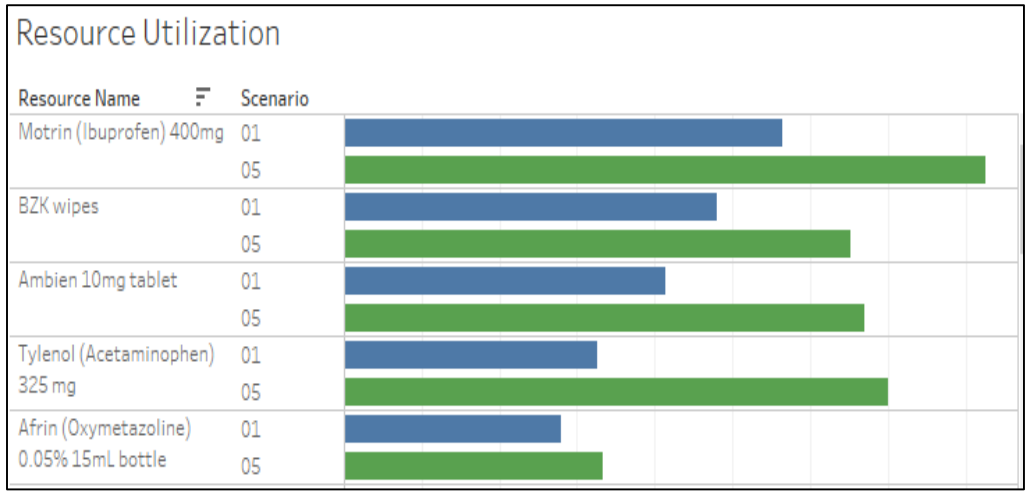


Tool Suite Description – Excel & Tableau

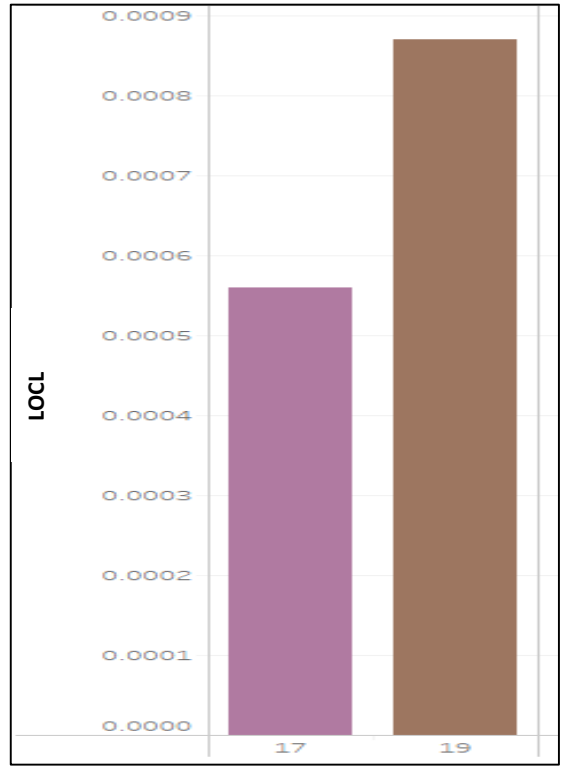
Selected capabilities of the post processing tools:

System Characteristic	System 1- Run 1	System 2-Run 2
Mass (kg)	115.2	106.6
Prob of Loss of Crew	0.0057	0.0061
Prob of EVAC	0.0999	0.101
Crew Health Index	0.929	0.928
Requirements not met	0	4
Conditions not addressed	0	32

System Characteristics: Shows scenario information in a table



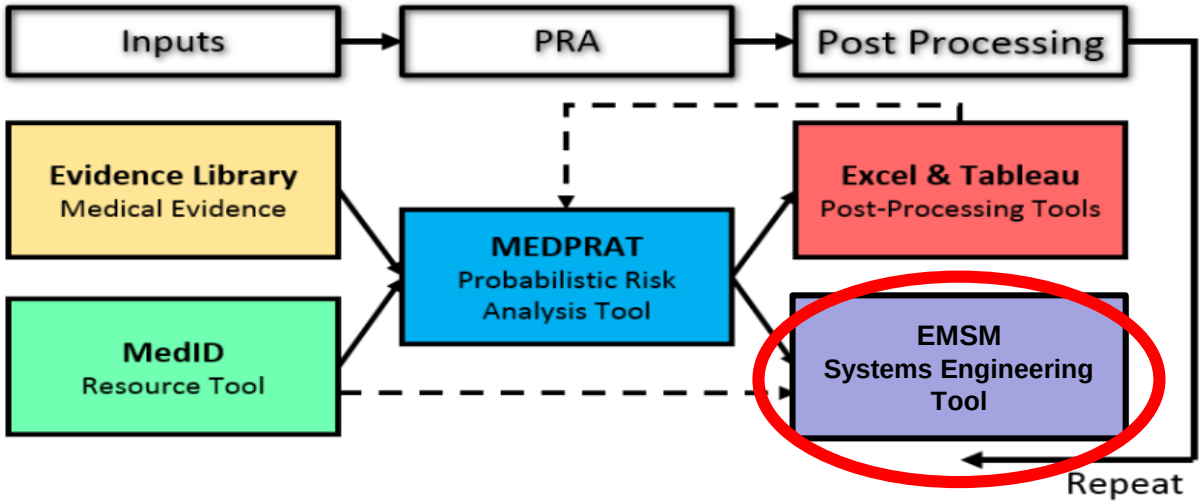
Resource Information: Shows the resource data by most utilized resource for multiple scenarios



Risk Information: Shows the ability to compare risk metrics for multiple scenarios

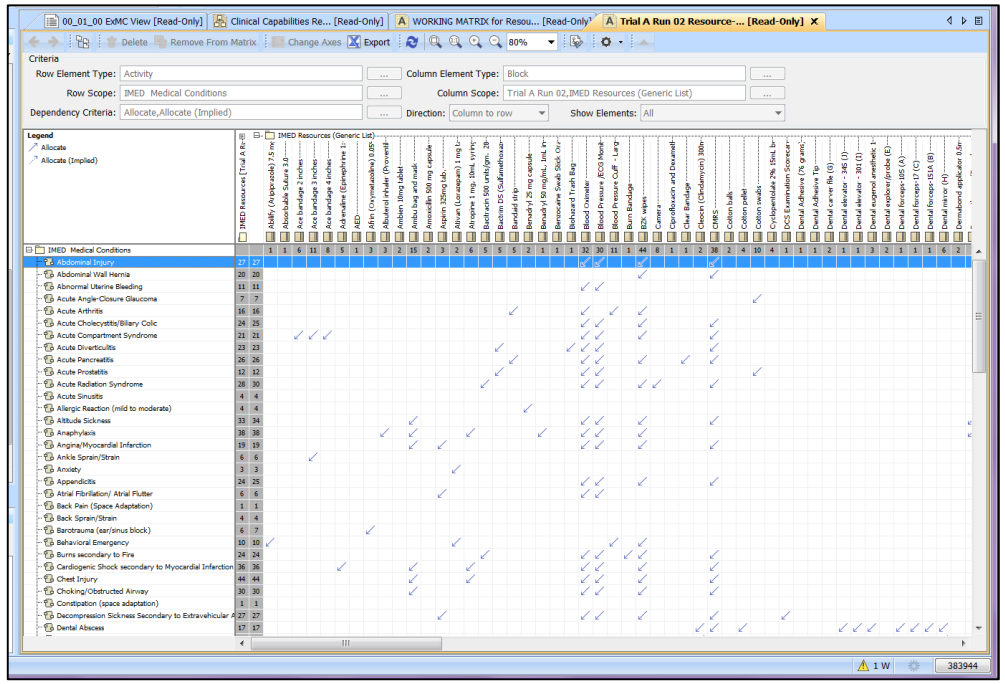
Tool Suite Description – EMSM

Exploration Medical System Model (EMSM)	– Houses the capabilities and requirements of the medical system – Produces reports of conditions/requirements that are satisfied by a candidate set of resources



Tool Suite Description – EMSM

Selected capabilities of the Exploration Medical System Model:



Dependency Matrix: Shows the relationship between medical resources and conditions

#	Name	Scenario 19 Items	Scenario 38 Items	Medical Conditions Trace	Requirements Trace	Resource Type
1	Abilify (Aripiprazole...			Behavioral Emergency	Hab-MedSys-Resources-0001 Provide Abilify (Aripiprazole) 7.5 mg/m	Abilify (Aripiprazole) 7.5 mg/mL, 1.3 mL
2	Absorbable Suture ...		ABSORBABLE SUTURE 3.0	Skin Laceration	Hab-MedSys-Resources-0002 Provide Absorbable Suture 3.0	Absorbable Suture 3.0
3	Ace bandage 2 inches		ACE BANDAGE 2 INCHES	Acute Compartment Syndrome Shoulder Dislocation Lower Extremity (LE) Stress Fracture Elbow Dislocation Hip/Proximal Femur Fracture Shoulder Sprain/Strain	Hab-MedSys-Resources-0003 Provide Ace bandage 2 inches	Ace bandage 2 inches
4	Ace bandage 3 inches		ACE BANDAGE 3 INCHES	Elbow Dislocation Lower Extremity (LE) Stress Fracture Shoulder Dislocation Wrist Sprain/Strain Knee Sprain/Strain Wrist Fracture Hip/Proximal Femur Fracture Acute Compartment Syndrome Elbow Sprain/Strain Shoulder Sprain/Strain	Hab-MedSys-Resources-0004 Provide Ace bandage 3 inches	Ace bandage 3 inches
5	Ace bandage 4 inches		ACE BANDAGE 4 INCHES	Hip/Proximal Femur Fracture Wrist Sprain/Strain Lower Extremity (LE) Stress Fracture Shoulder Sprain/Strain Elbow Dislocation Elbow Sprain/Strain Acute Compartment Syndrome Shoulder Dislocation	Hab-MedSys-Resources-0005 Provide Ace bandage 4 inches	Ace bandage 4 inches
6	Adrenaline (Epinep...	Adrenaline (Epinephrine 1:	ADRENALINE (EPINEPHRI	Cardiogenic Shock secondary to Myocard Sepsis Traumatic Hypovolemic Shock Neurogenic Shock Sudden Cardiac Arrest	Hab-MedSys-Resources-0006 Provide Adrenaline (Epinephrine 1:10(	Adrenaline (Epinephrine 1:10000) 10mL

Impacted Medical Condition List: Shows the impact of the removal of medical resources on condition treatment capabilities and requirements satisfaction (SysML & Excel)

Tool Suite Pilot Project

Phase I & Phase II

Tool Suite Pilot Project Goals

Phase I:

- Demonstrate the **ability** for the user to **interact** with the tool suite to produce outcomes
  - Medical Equipment List (MEL)
  - Risk parameters
  - Medical system requirements satisfaction
  - Medical conditions addressed

Phase II:

- Demonstrate the medical system **optimization**
- Show tool and team **integration**
- Perform **more substantial** trade analyses

Tool Suite Pilot Project Scenarios

	Trial	DRM	Medical Capability	Trade Scenarios	Outcomes
Phase I (2 trials)	A	42 days 4 crew - 1 female EVAs	ISS medical kit	Remove space motion sickness medications from a baseline medical set and determine outcomes	Removing meds resulted in increases in LOCL, QTL, and RTDC
	B	365 days 6 crew - 1 female EVAs	ISS medical kit	Remove a significant portion of mass/volume by eliminating defibrillator and oxygenation hardware	• Removing equipment resulted in non-significant increases in LOCL, QTL, and RTDC • 32 conditions no longer addressed
Phase II (7 trials)	C	42 days 4 crew - 1 female EVAs	Updated medical set from MedID	Investigate effects of: • Extend mission to 90 days • With/without EVAs • With/without RTDC option • With/without pre-existing conditions among crew members	• Mission duration increase from 42 days to 90 days contributed significantly to increased risk • Other effects did not significantly affect risk factors for a 42 day mission • High variance in outcomes, especially LOCL
	D	42 days 4 crew - 1 female No EVAs	Optimized version of Trial C	• Optimize to meet a mass target only. Reduce baseline mass target by 12.5% and 25%. • Optimize each combination within acceptable LOCL only, then within acceptable QTL only	• Optimizing to meet a mass target for LOCL only resulted in unacceptably high QTL • Optimizing for QTL only still resulted in acceptable LOCL
	E	42 days 4 crew - 1 female No EVAs	Optimized version of Trial C	• Optimize to meet a volume target only. Reduce baseline volume target by 12.5% and 25%. • Optimize each combination within acceptable LOCL only, then within acceptable QTL only	• Optimizing to meet a volume target for LOCL only resulted in unacceptably high QTL • Optimizing for QTL only still resulted in acceptable LOCL
	F	42 days 4 crew - 1 female No EVAs	Optimized version of Trial C	• Optimize to meet a weighted combination of mass and volume targets. • Optimize each combination within acceptable LOCL only, then within acceptable QTL only	• Optimizing to meet a combined mass and volume target for LOCL only resulted in unacceptably high QTL • Optimizing to meet a combined mass and volume target for QTL only still resulted in acceptable LOCL • Better overall solution when volume weighting was higher relative to mass
	G	42 days 4 crew - 1 female No EVAs	Optimized version of Trial C	Optimize to meet mass target or a weighted combination of mass and volume targets and a weighted combination of acceptable risk thresholds.	• A weighted combination of risk thresholds resulted in the ability to meet both simultaneously • Better overall solution when volume weighting was higher relative to mass
	H	42 days 4 crew - 1 female No EVAs	Optimized version of Trial C	Optimize to meet a mass target with the two heaviest items reduced in mass and volume by 80% each through technology development	• An 80% reduction in mass of two bulky items permits their inclusion in the medical system and enables medical requirements to be met that were previously not being met, while maintaining acceptable risk
	I	42 days 4 crew - 1 female No EVAs	Optimized version of Trial C	Determine the weighting coefficients required to meet mass and volume targets as well as acceptable thresholds for LOCL and QTL simultaneously.	• It was possible to meet mass and volume targets within acceptable risk thresholds for LOCL and QTL • The target for volume requires a higher weighting because it constrains the medical system more than the target for mass

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Tool Suite Pilot Project Success Criteria

Phase I:

✓Given a Design Reference Mission, produce the following **outputs**:

- Medical Equipment List (MEL)
- Risk parameters
- Medical system requirements satisfaction
- Representative medical conditions addressed

✓Ensure **consistent** data products across tools and team

✓Produce results **quickly**

✓Document **lessons learned**

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  - Representative medical conditions addressed
- ✓Ensure **consistent** data products across tools and team
- ✓Produce results **quickly**
- ✓Document **lessons learned**

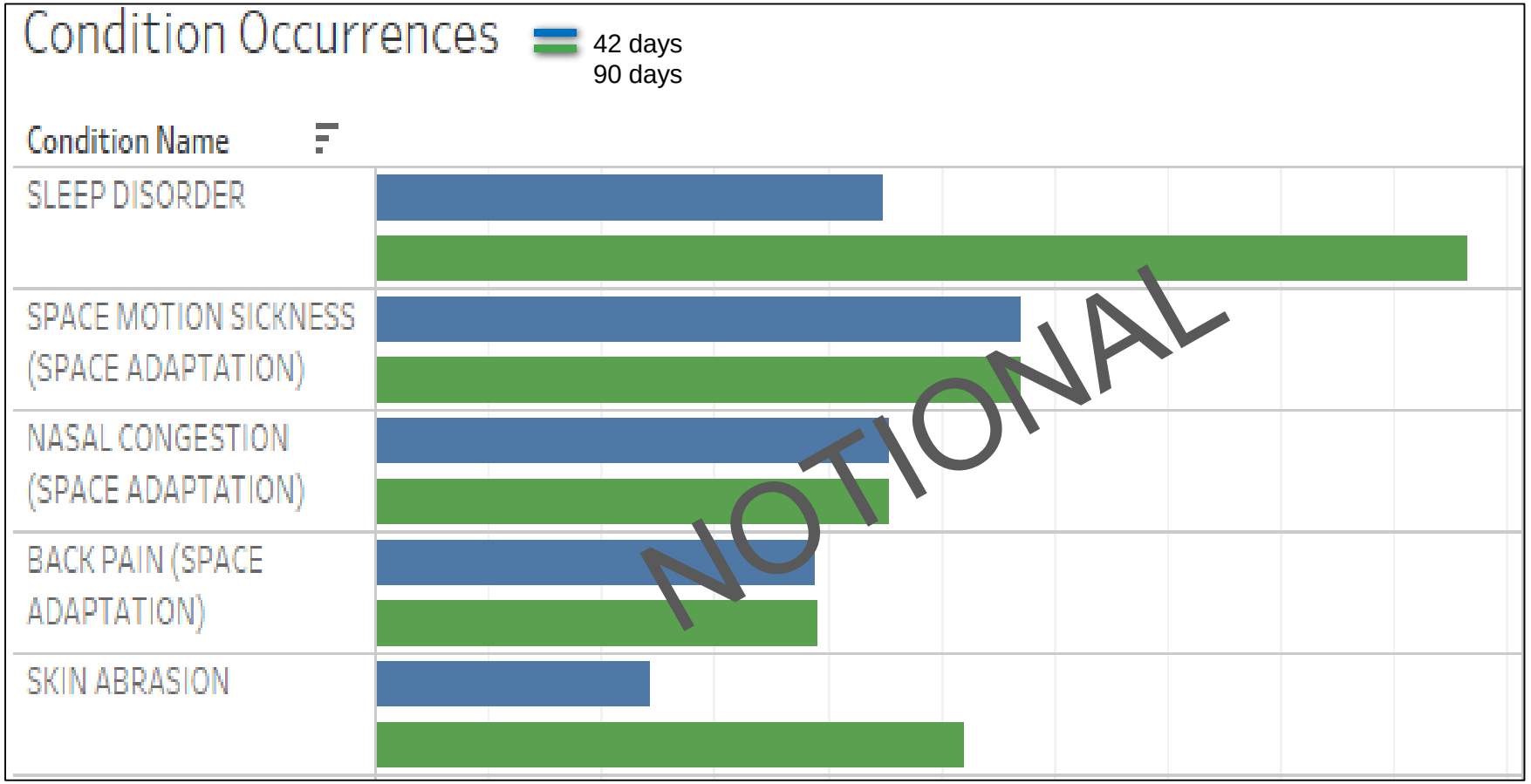
Phase II:

- ✓Demonstrate the effectiveness of **new features and enhancements** to the tool suite
  - Optimization
  - Requirements and conditions in EMSM
- ✓**Integrate** the tools better into a well-functioning whole
- ✓Develop **post-processing tools** that facilitate efficient and effective interpretation of results from the tool suite

Significant Findings of Pilot Project Phase II

Post-processing in Tableau makes it easy to determine information about:

- Conditions



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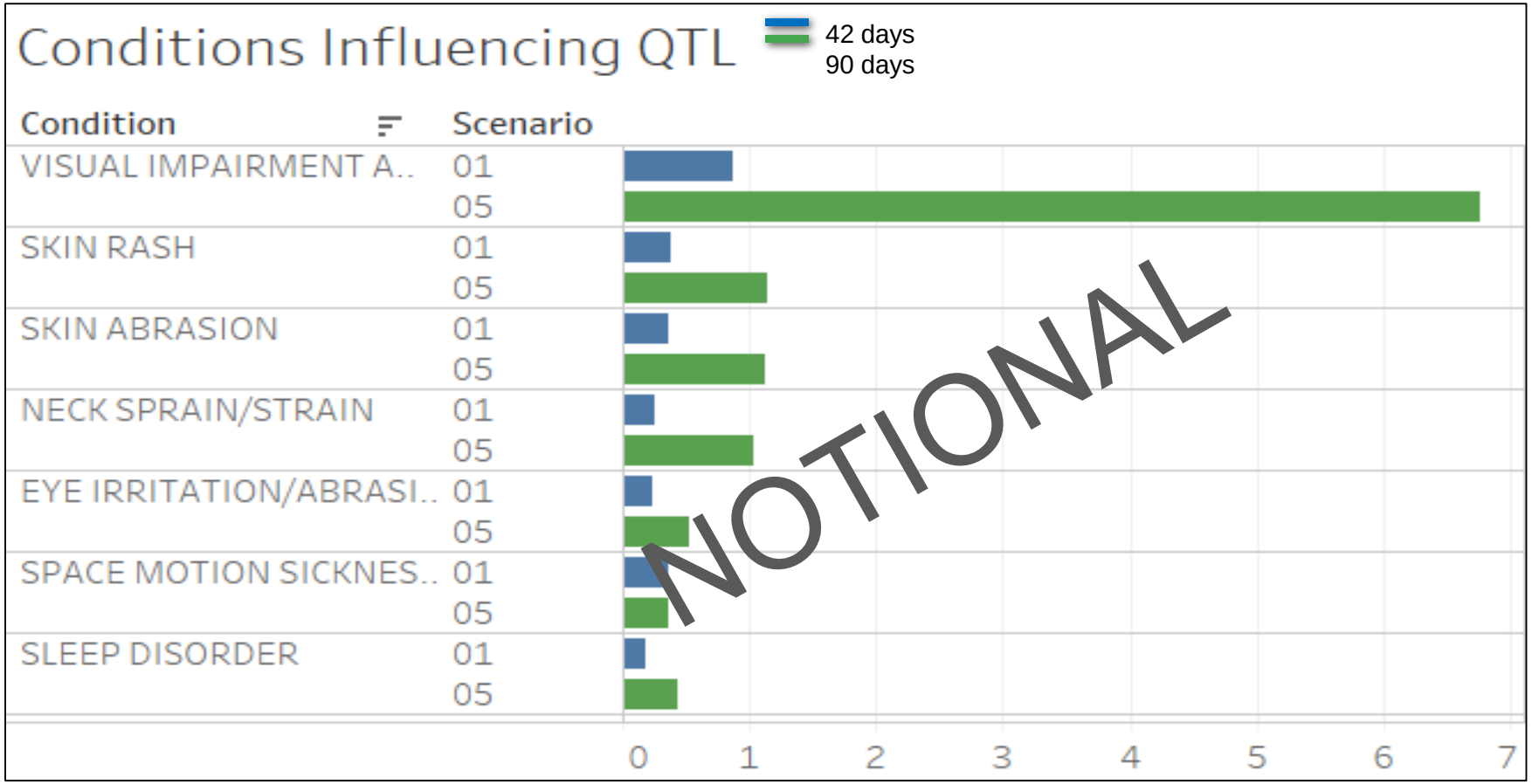
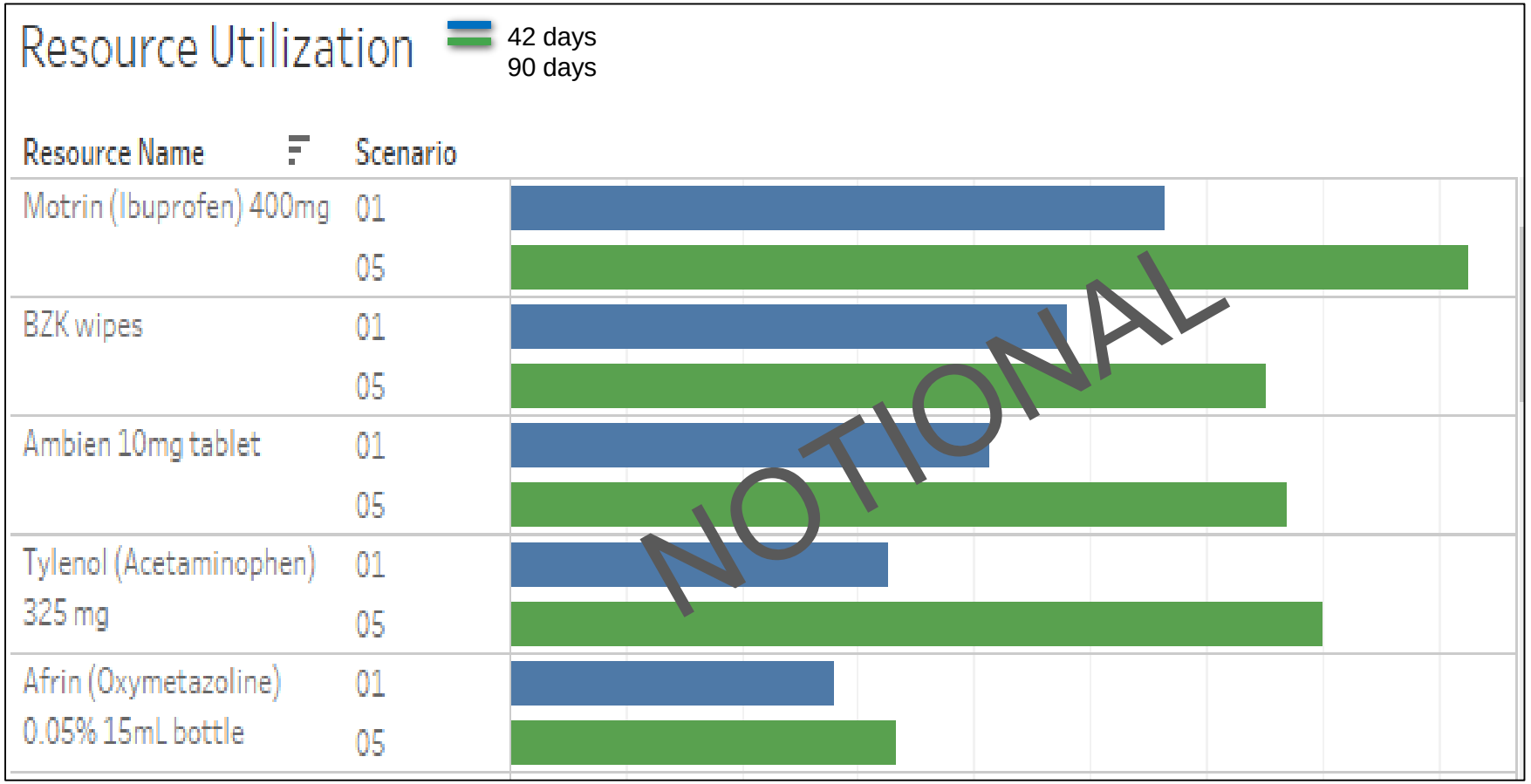


Significant Findings of Pilot Project Phase II

Post-processing in Tableau makes it easy to determine information about:

- Conditions
- Risks
- Resources



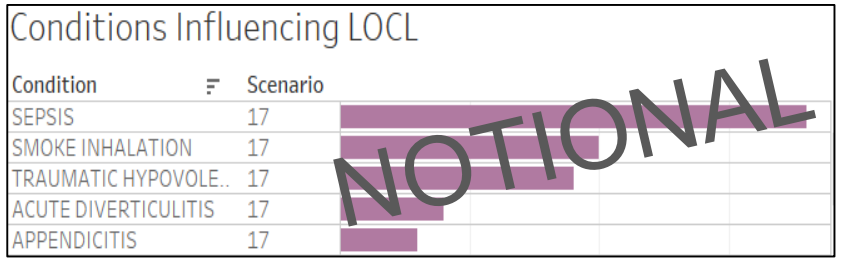
Summary of Results

- The tool suite is providing results that **meet clinician face validation** based on the input conditions and assumptions
- The tools are working together well, with **opportunities** for further integration and automation
- We have **identified the process** necessary for using the tools to achieve results for some very **specific** and **useful** types of trades
  - Technology Development
  - Medical set optimization and fine tuning
- Pilot projects phase I and II have **fully met the success criteria**

Summary of Results

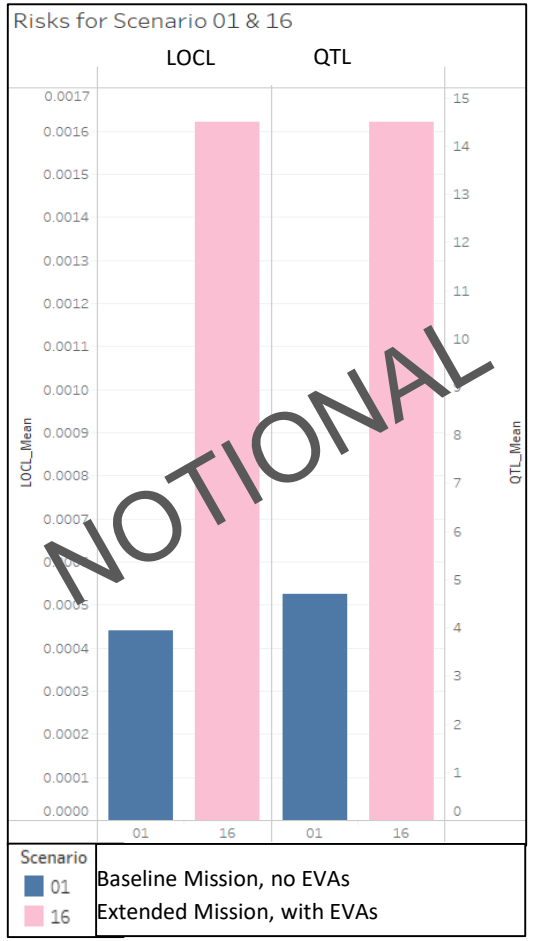
For any given mission with defined number/gender of crew, pre-existing conditions, mission duration, extra-vehicular activity, and starting medical capabilities, the tool suite can:

- ✓ Identify a nearly optimal set of medical resources
- ✓ Identify system requirements and requirement satisfaction
- ✓ Identify medical conditions that will occur
- ✓ Identify medical capabilities that will be met/unmet
- ✓ Meet all notional targets
- ✓ Meet all notional constraints



Analysis Results:	Trial B Run1	Trial B Run 2
1. Number of requirements missing from the trial run compared to the generic list:	0	4
Trial B Run 1 Missing Requirements:		
Trial B Run 2 Missing Requirements:	Provide AED	
	Provide Blood Oximeter	
	Provide Variable Oxygen System	
	Provide VOS Intubated Patient Hardware (Ventilator/Respirator)	

NOTIONAL



Significance

- Identify which medical capabilities have the potential to provide the **greatest possible risk reduction benefit**, leading to an increased likelihood of their inclusion in exploration medical systems.

- Can inform NASA mission developers regarding the **prioritization of research and technology development** for deep space medical capability.

- Enables human health and performance to be considered as early as possible in the mission planning and vehicle design process, allowing for **full integration into architectures** as they are conceptualized, developed, and adopted.

Limitations of Work

- Limitations of the individual tools

Evidence Library	**Updates** to condition incidence rates used by MEDPRAT, **updates** to conditions to consider, and **updates** to treatment and resource capabilities are in process.
MedID	The **ServiceNow** platform used in Phase II was not as configurable as previously expected. The team is moving towards using an **SQL** database.
MEDPRAT	The capability to capture **condition interdependencies** is in development.
Excel & Tableau	The stakeholders need to have the **appropriate software** to view results.
EMSM	The requirements set is still in development, resulting in **incomplete tracing** among all applicable requirements.

- Folder structures were inconsistent
- Learning curve for the tools
- Geographically distributed team

Future Work

- **Technology assessments** of candidate components
- Medical **component characteristics** to be incorporated
- **Automation** of data exchange and operation, including **integration scripts**
- Development of **evidence base and models** for MEDPRAT
- **Bundling** resources together using resource dependencies
- Simulation of **longer duration missions** with potential **new capabilities**

Thank you!
Questions?

Please contact us!

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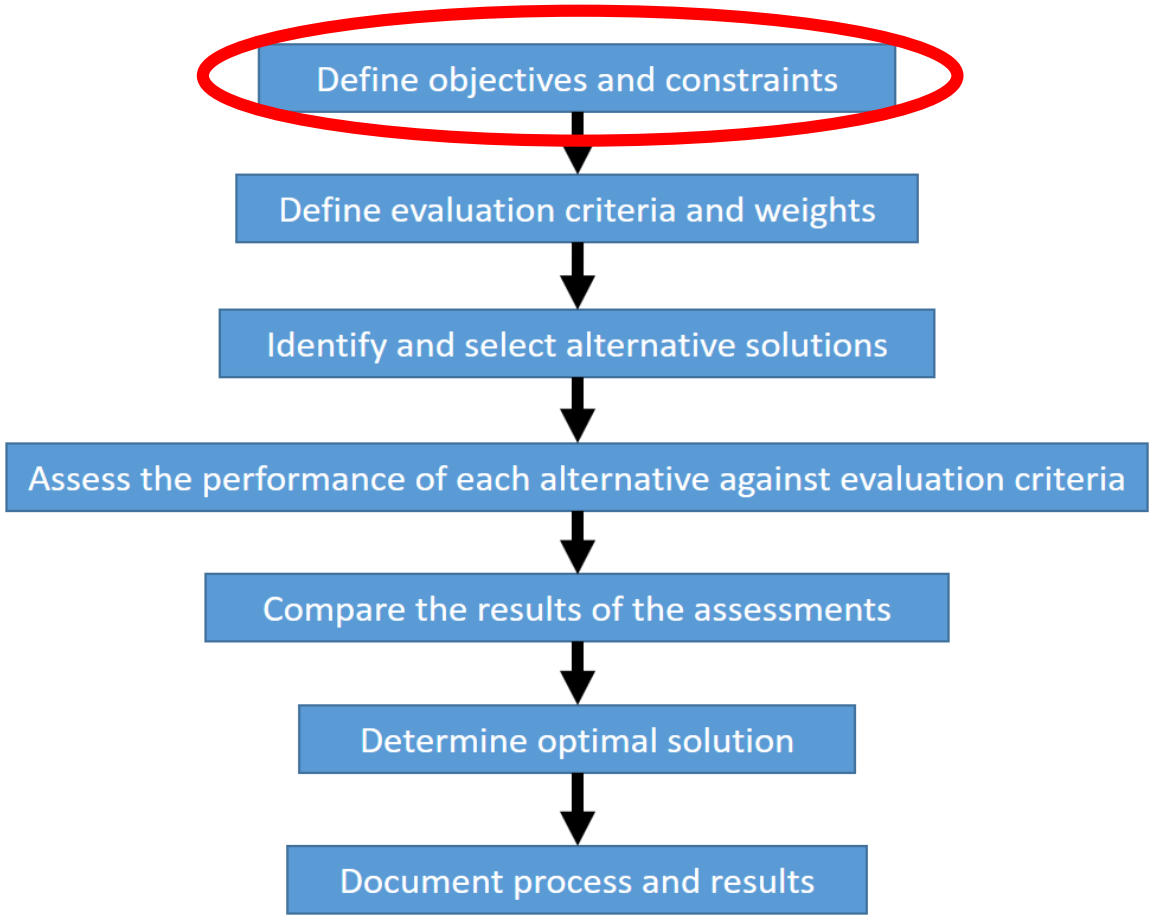
Jennifer Mindock – jennifer.a.mindock@nasa.gov

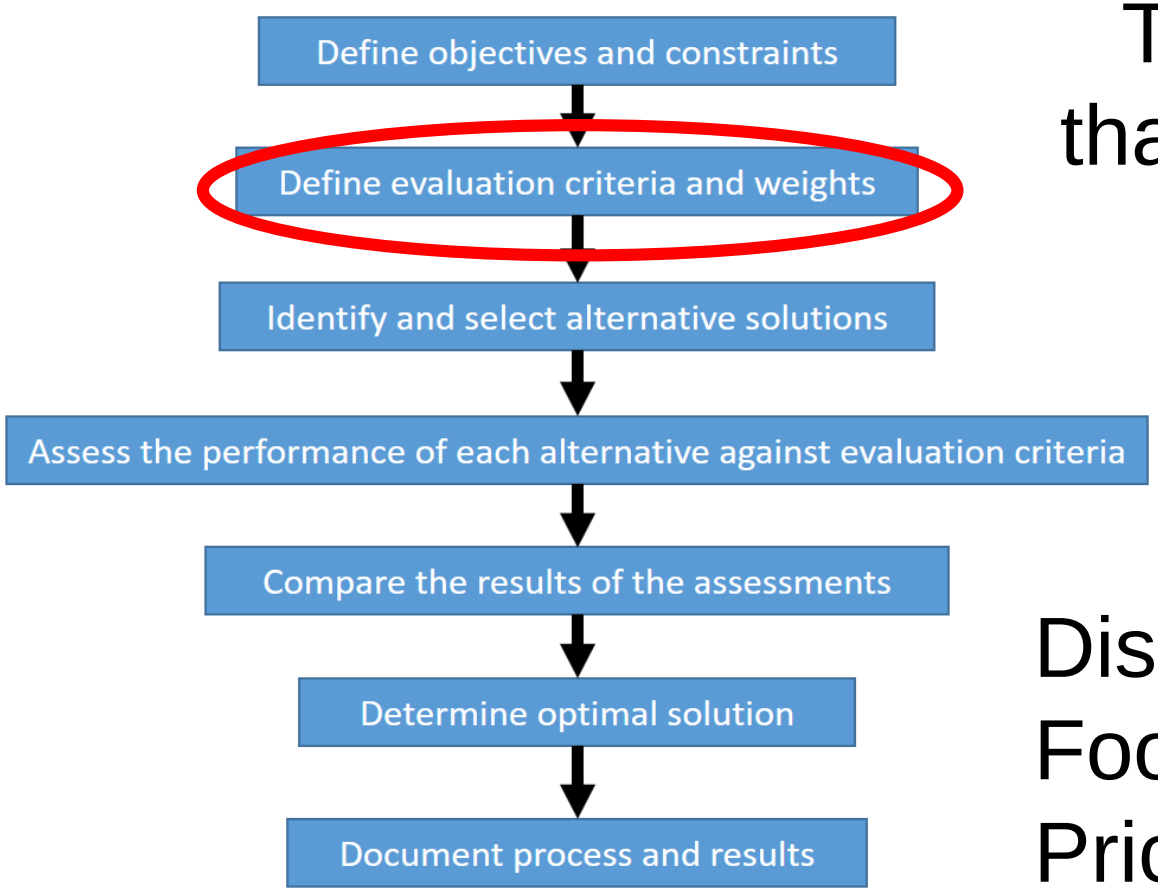
Backup Slides

Trade Study Overview



I want to go out to eat for dinner.

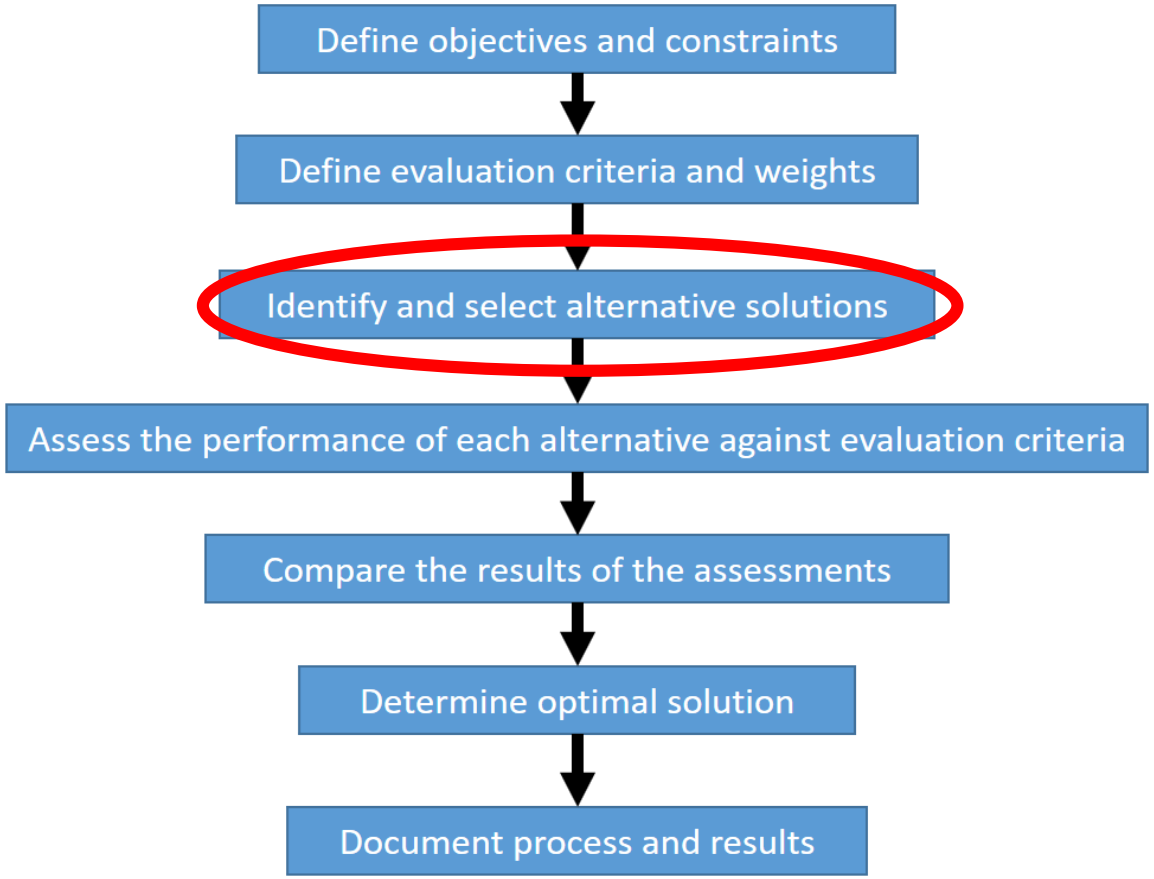
Trade Study Overview



The restaurant must be less than 10 miles from my location, have good food, and be reasonably priced.

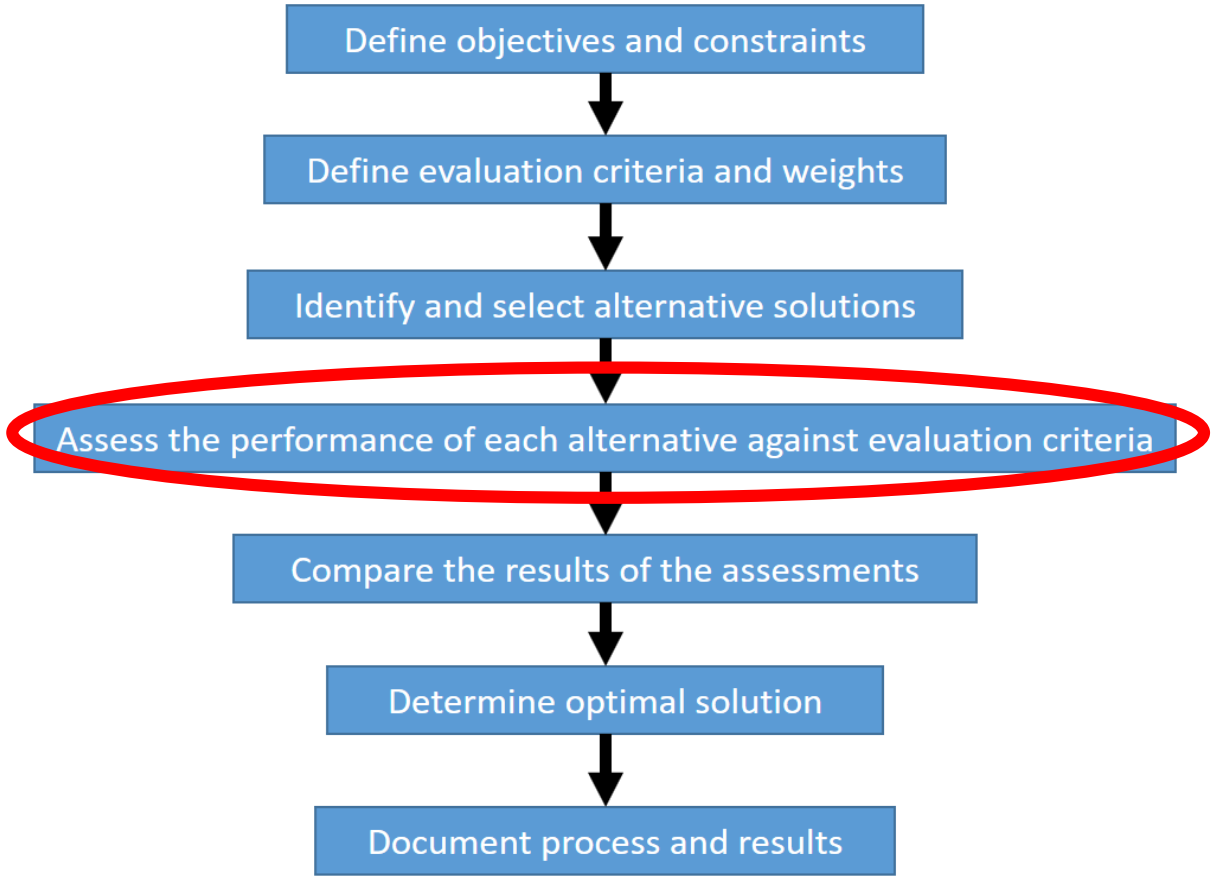
Distance: 1 (least important)
Food Quality: 3 (most important)
Price: 2

Trade Study Overview



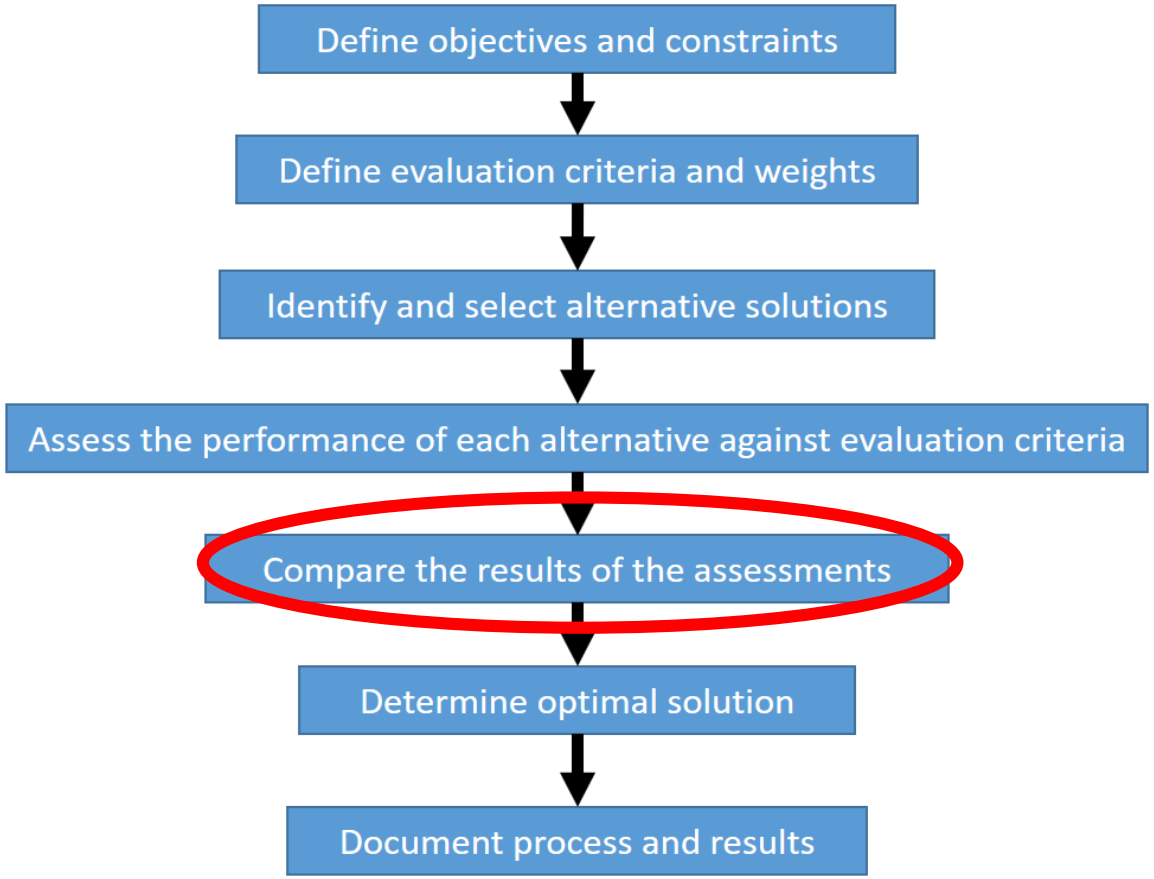
1) Fast Food
2) Local Restaurant
3) Banquet Hall

Trade Study Overview



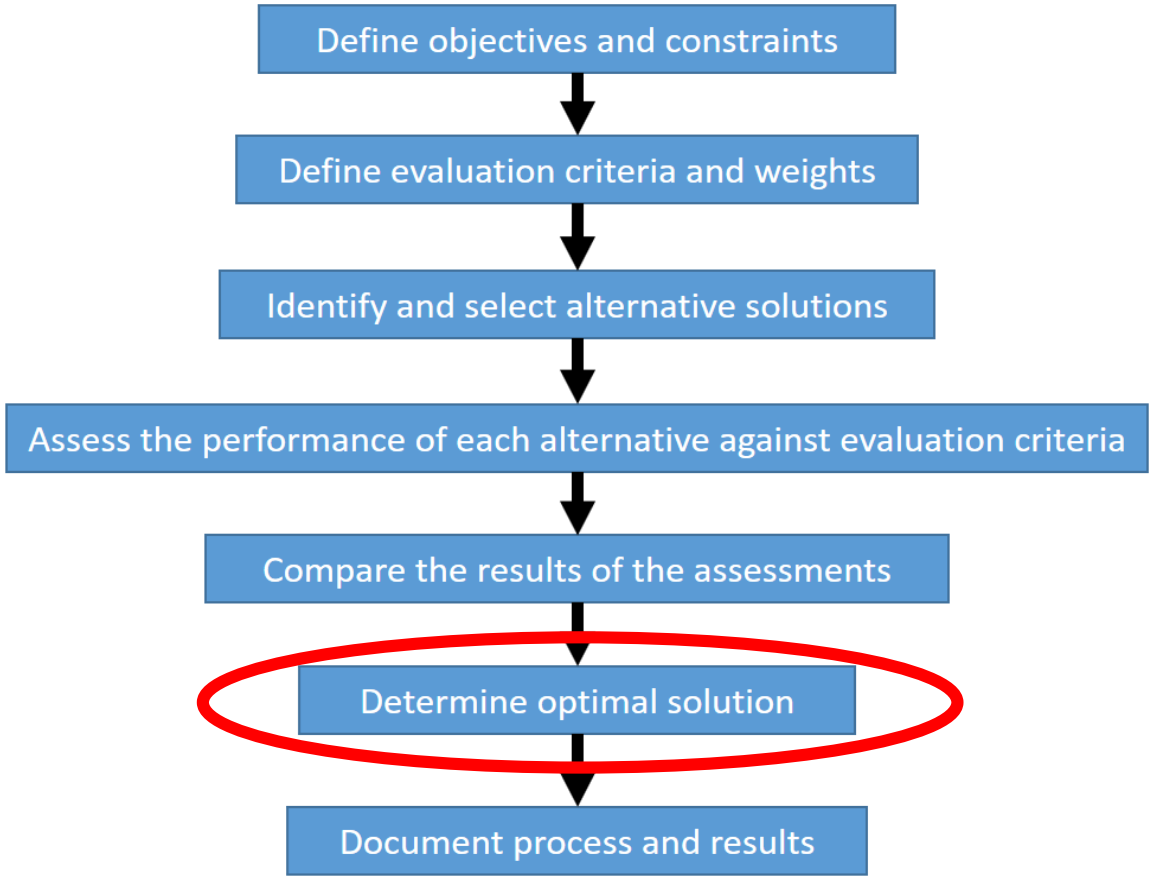
1) Fast food: .5 miles away with low quality food, very cheap.
2) Local restaurant: 12 miles away with good quality food, moderately priced.
3) Banquet hall: 7 miles away with moderate quality food, very expensive.

Trade Study Overview



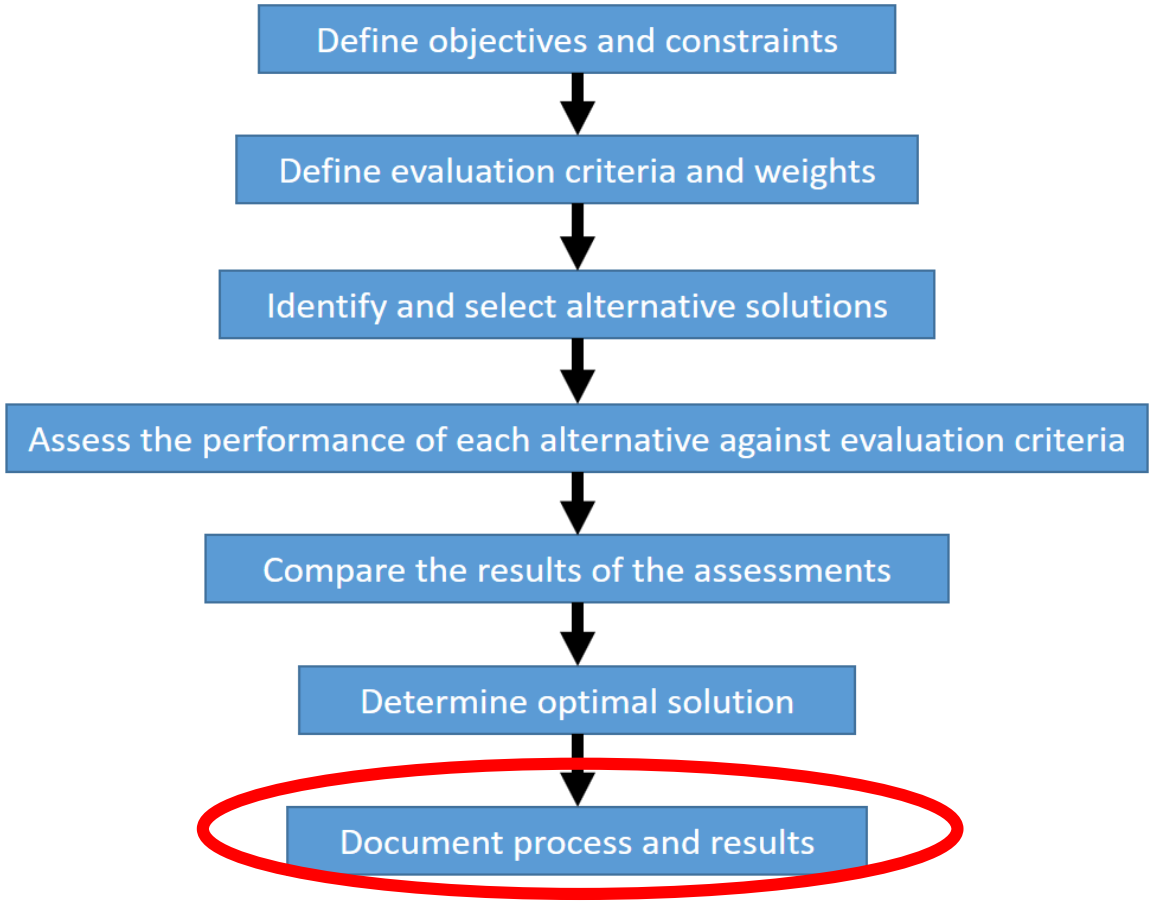
	Distance (1)	Food Quality (3)	Price (2)	Total Score
Fast Food	3	1	3	12
Local Restaurant	2	3	2	15
Banquet Hall	1	2	1	9

Trade Study Overview



	Distance (1)	Food Quality (3)	Price (2)	Total Score
Fast Food	3	1	3	12
Local Restaurant	2	3	2	15
Banquet Hall	1	2	1	9

Trade Study Overview



This information needs to be accessible so that I can make this same decision again next week with different restaurants!

Potential Stakeholders of the Tool Suite

Potential Stakeholders	Life Cycle Phase	Scenario
OCHMO, MedOps	Pre-Phase A	Condition likelihoods with level of care definitions
Exploration Program Systems Engineering Team	Pre-Phase A	Mass and volume allocation
ExMC Leadership	Pre-Phase A	Research prioritization
HRP Elements	Pre-Phase A	Risk assessment
Mars Program CHP System Management	Phase A	Requirements development
Exploration Program CHP System Management, Exploration Program Management	Phases B/C	Trade analysis to identify system resources
Mars Program Management, MedOps	Phase D	Updated risk impact just prior to mission
MedOps, OCHMO, Lunar Program Management, Lunar Program Medical System Management	Phase E	Updated risk impact if new condition occurs, using real-time inventory