National Aeronautics and Space Administration

Exploration Medical Capability Systems Engineering Overview and Update

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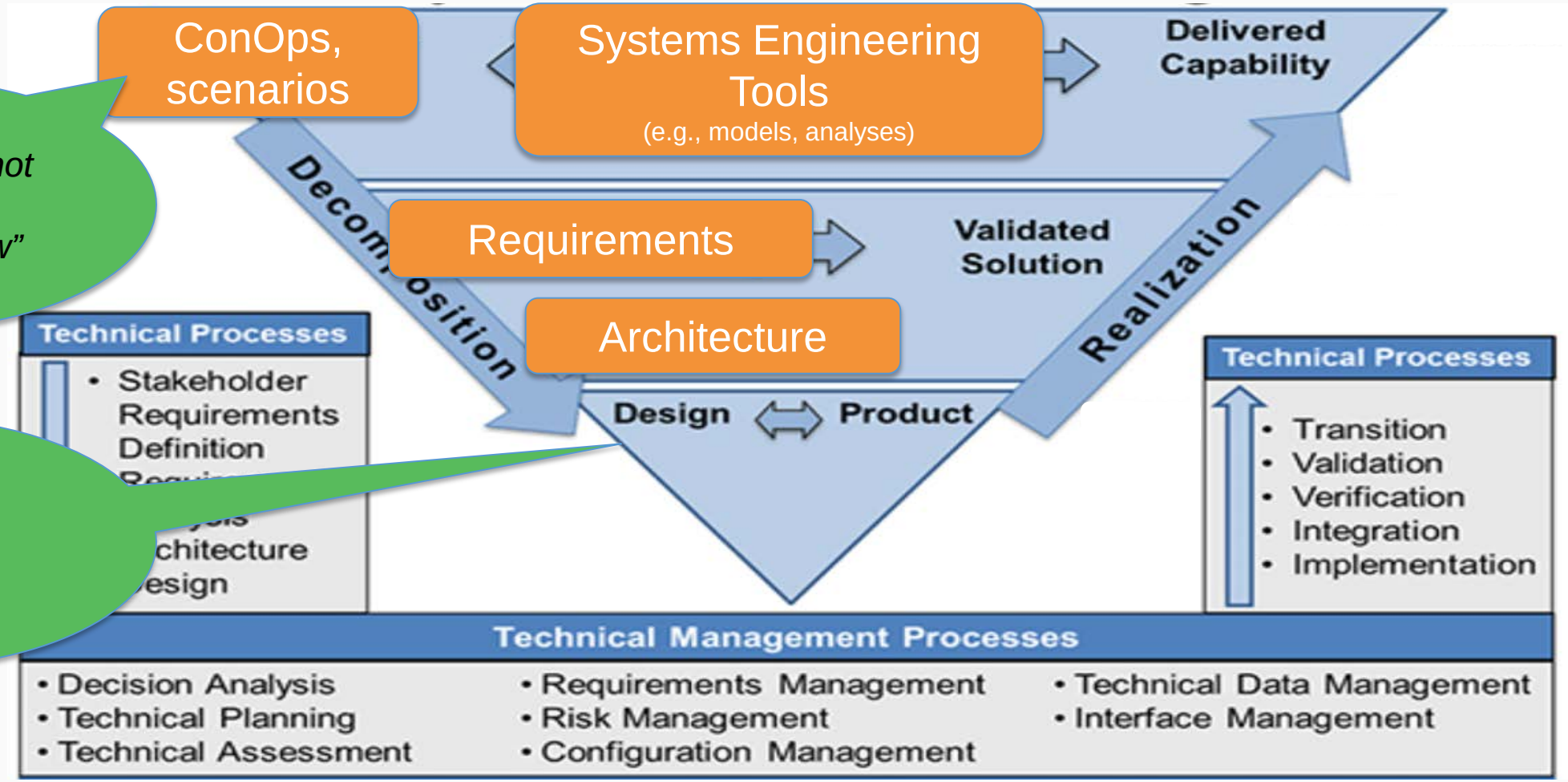
January 22 - 25, 2019 | Galveston Island Convention Center

Why Systems Engineering?

We must communicate with exploration mission development activities effectively

"Problem space, not solution space"
Or "What, not How"

Do we have solutions? If no, research and tech dev required!



https://dap.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=9c591ad6-8f69-49dd-a61d-4096e7b3086c

ExMC SE Mission – 2+ years later still holds

Define, develop, validate, and manage the technical system design needed to implement exploration medical capabilities for Mars and test the design in a progression of proving grounds.

Needs

Develop system technical foundation

- Develop ConOps
- Capture stakeholder expectations
- Define and manage requirements
- Capture and share system design
- Identify and manage cross-disciplinary interfaces
- Plan and execute system
- Inform system developm
  from scientific, technical perspective
- Identify tech dev and research needs

Approach

Apply structured, integrative science and engineering

- Use a structured and disciplined approach to develop a med system addressing medical, behavioral health, human factors, physiological performance, and task performance needs to ensure crew health and
  integration with exploration mission engineering, operational, and technology development efforts

Benefit

Increase relevancy to exploration system maturation

- Speak the same language as engineering and operations communities with respect to system design
- Provide regular and transparent communication to maintain
  insight into the med system development
- Develop and foster shared mental models within and external to crew health and performance community

Culture

Be open, unbiased, learning, and serving

- Develop relationships across disciplines and Centers to build trust and enable teamwork
- Enhance visibility and opportunities for influence on concurrent activities of related groups that otherwise would
  E principles and practices
- Be both responsive to and anticipatory of stakeholder needs, keeping in mind stakeholders may be from anywhere in an org chart

See our Systems Engineering Management Plan (SEMP)!

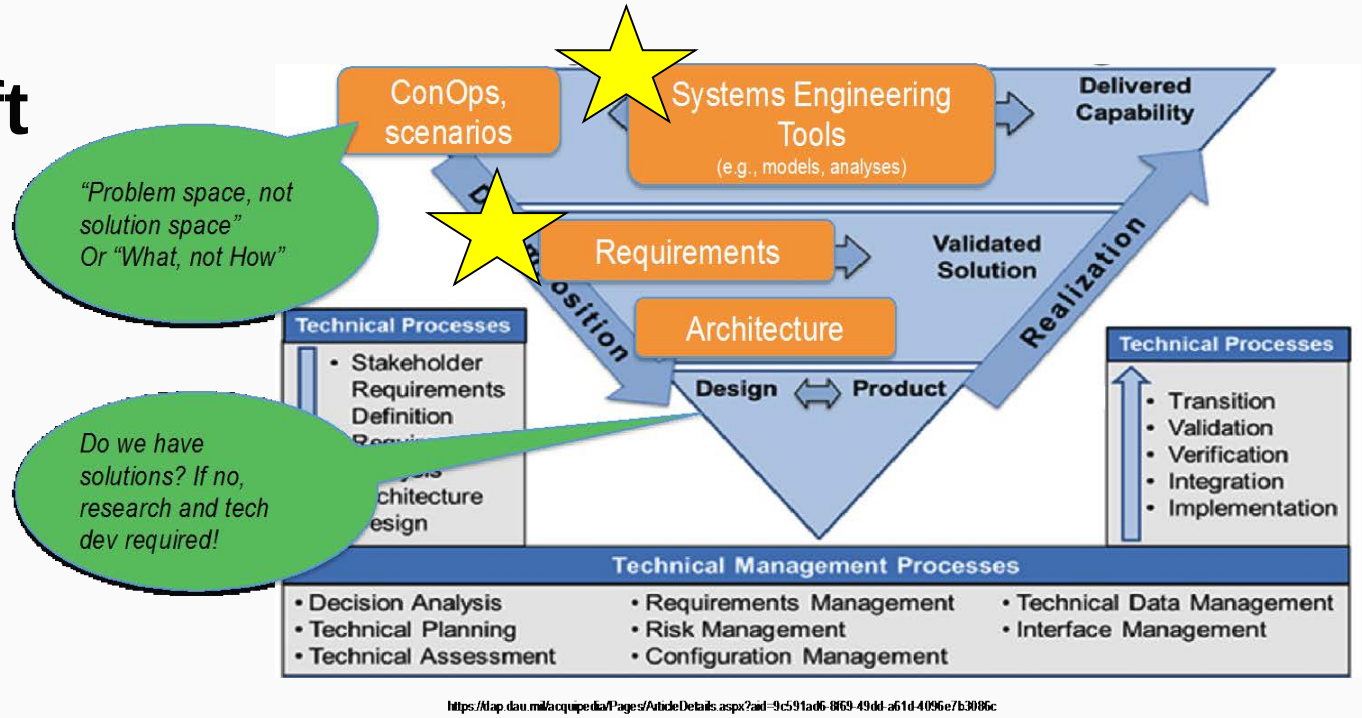
Growth

	Late FY16	FY17	FY18	FY19
Team members: (not full time)	4	11	> 30	
Example Products:	• Systems Engineering Mgmt Plan…	• Team infrastructure • Mars transit medical ConOps • Prototype SysML model • System needs and goals • Initial system functions • Initial system description…	• Expanded team infrastructure • Lunar vicinity Level 4 med ConOps • Lunar vicinity med SysML model • Lunar vicinity med system needs and goals • Lunar vicinity med system functions • Lunar vicinity med system description • Lunar vicinity med conditions list • Lunar vicinity planned and unplanned med capabilities • Lunar vicinity draft med system functional requirements • Medical system trade study tools pilot • …	
Collaborations:	• JSC SD, SF, SK	• ARC, GRC, LaRC • SMT, CSA, ESA • iPAS (JSC Engineering) • MBSE – JSC, NASA • JSC SD, SF, SK • ECLSS, Avionics	• ARC, GRC, LaRC • SMT, CSA, ESA • iPAS (JSC Engineering) • MBSE – JSC, NASA • JSC SD, SF, SK • ECLSS, Avionics • HRP PSMO, Elements • Gateway, Exploration	

Charge since last IWS

1. **Habitat Medical System Draft Functional Requirements**

1. **Systems Engineering Tools Maturation**



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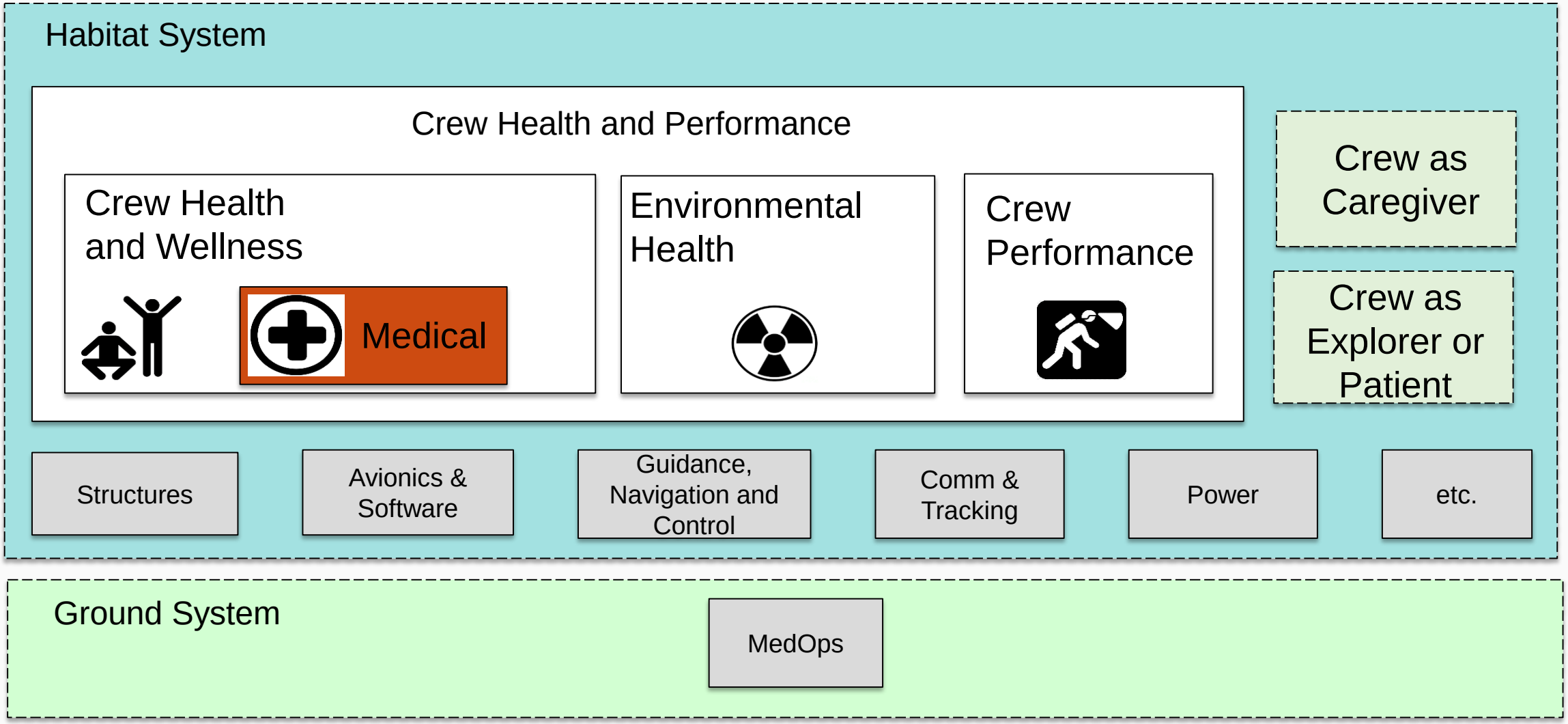
Applying Systems Engineering to Integrate – Context in Representative System



Team activities to get to requirements

Medical Domain Activities

NASA-STD-3001 Interpretation

History of conditions (IMM)

Accepted Medical Condition List

Planned activities

Unplanned activities

Team works closely together

Med Sys Capabilities

Med Sys Resources

Sys Eng Activities

DRM Inputs

Higher Level Requirements
(not yet available)

Med Sys ConOps

Med Sys Functions

Med Sys Functional Requirements

Med Sys Detailed Requirements

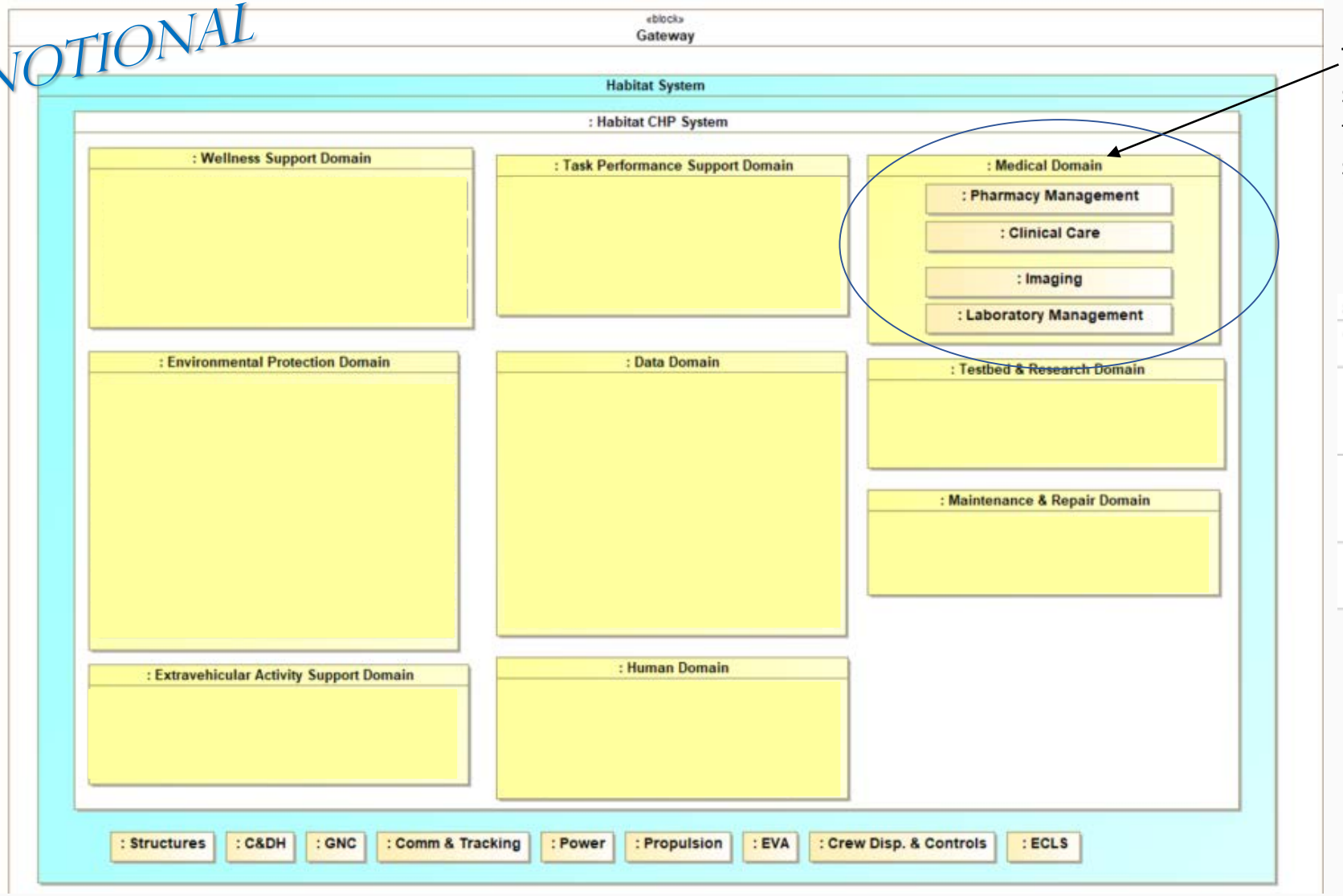
Do we have the capabilities to meet the needs?
Do we need altered allocations?

Concept of Operations

- Provides a **vision** for the system within the design reference mission of interest
- Defines the problem space, not solution
- Informs the ExMC systems engineering effort, providing a foundation
  - on which human-centered activities should be developed
  - used to derive system functions & requirements for the medical system.

See IWS talk on the ConOps development!

Architecture in ConOps and system model



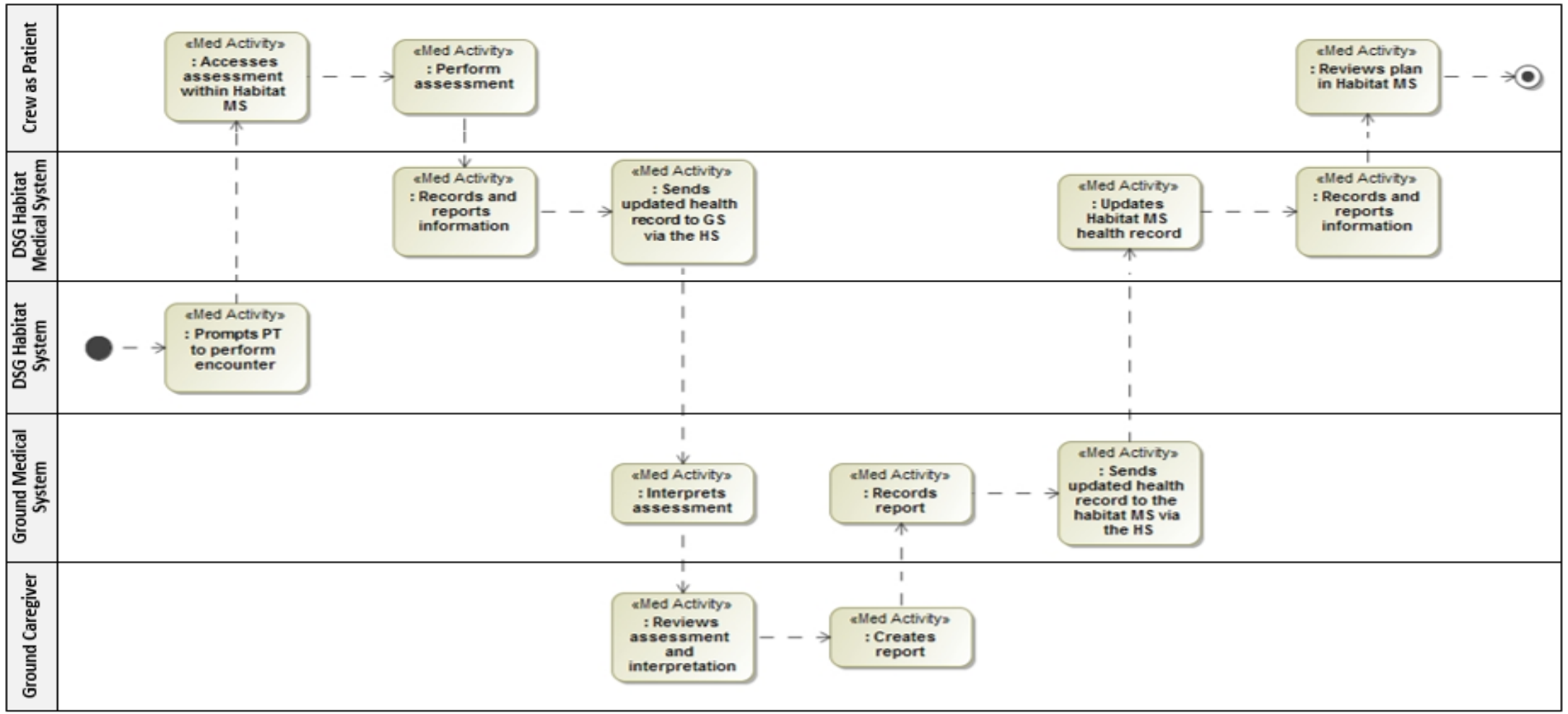
The Medical System architecture defines subsystems/subdomains and gives the framework for requirements, which then evolve into the solutions (hardware/software resources) for implementation.

Example system description:

Subdomain	Description
Clinical Care	Provides in-flight capabilities for the prevention, diagnosis, treatment, monitoring, and long-term management of medical conditions.
Imaging	Provides in-flight capabilities for diagnostic imaging in support of the provision of clinical care. Includes all hardware, software, and analysis capabilities required for the capturing and processing of diagnostic images.
Laboratory Management	Provides in-flight capabilities for laboratory analysis in support of the provision of clinical care. Includes all hardware, software, and analysis capabilities required for the collection and processing of biological samples.
Pharmacy Management	Provides in-flight capabilities for the administration of pharmaceuticals in support of clinical care. Includes all medications and the mechanisms used to prepare and deliver them and track their use.

- **Allows team to iterate and converge on same understanding of system architecture**
- **Supports negotiating interfaces between elements**

ConOps content in system model



- Team converges on same understanding of behavior and terminology
- Analysis of scenarios supports identification of needed functions

Team activities to get to requirements

Medical Domain Activities

NASA-STD-3001 Interpretation

History of conditions (IMM)

Accepted Medical Condition List

Planned activities

Unplanned activities

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Med Sys Capabilities

Med Sys Resources

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Higher Level Requirements

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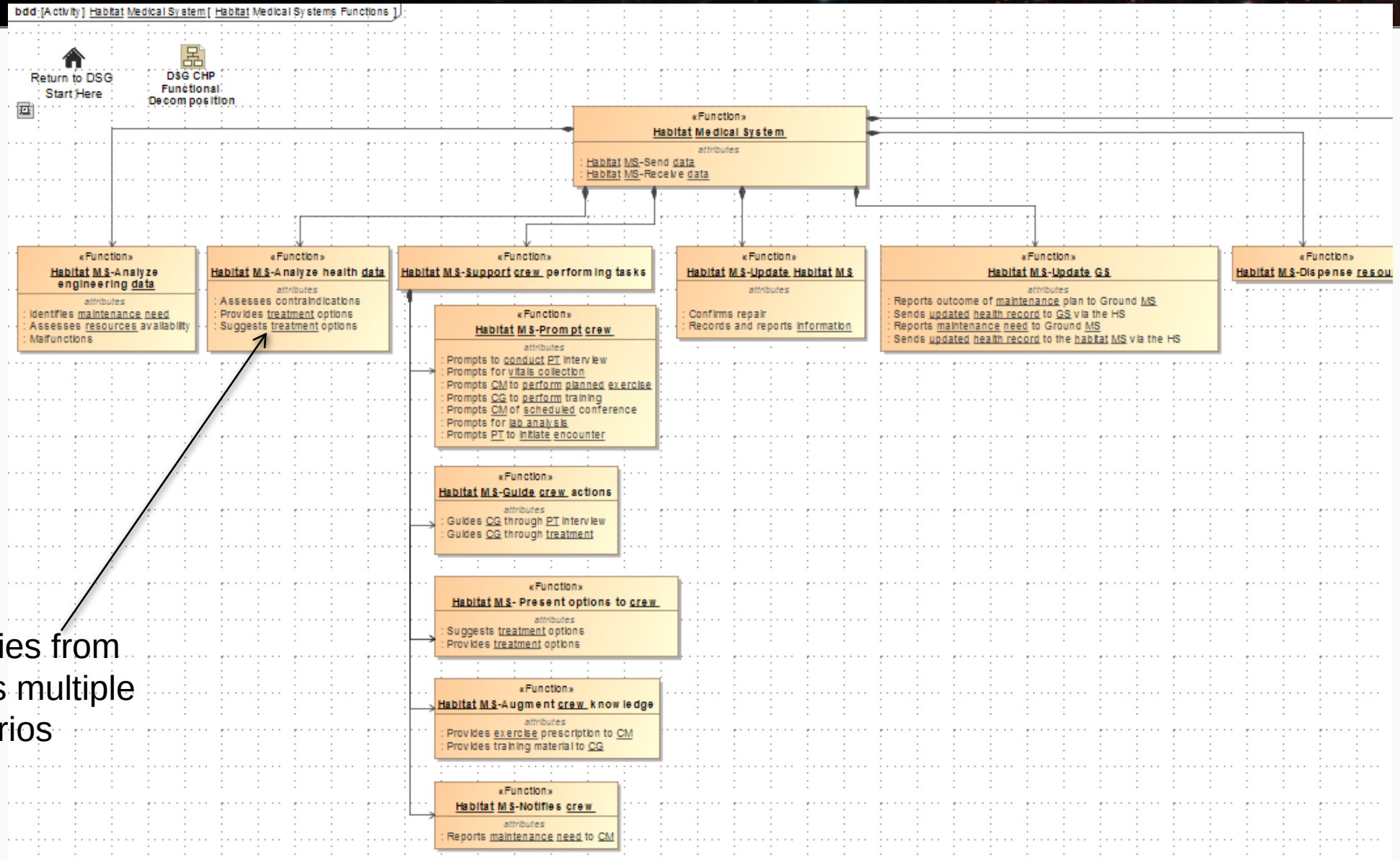
Med Sys Detailed Requirements

Do we have the capabilities to meet the needs?
Do we need altered allocations?

Thematic Analysis[1] → Medical System Functions



Activities from across multiple scenarios

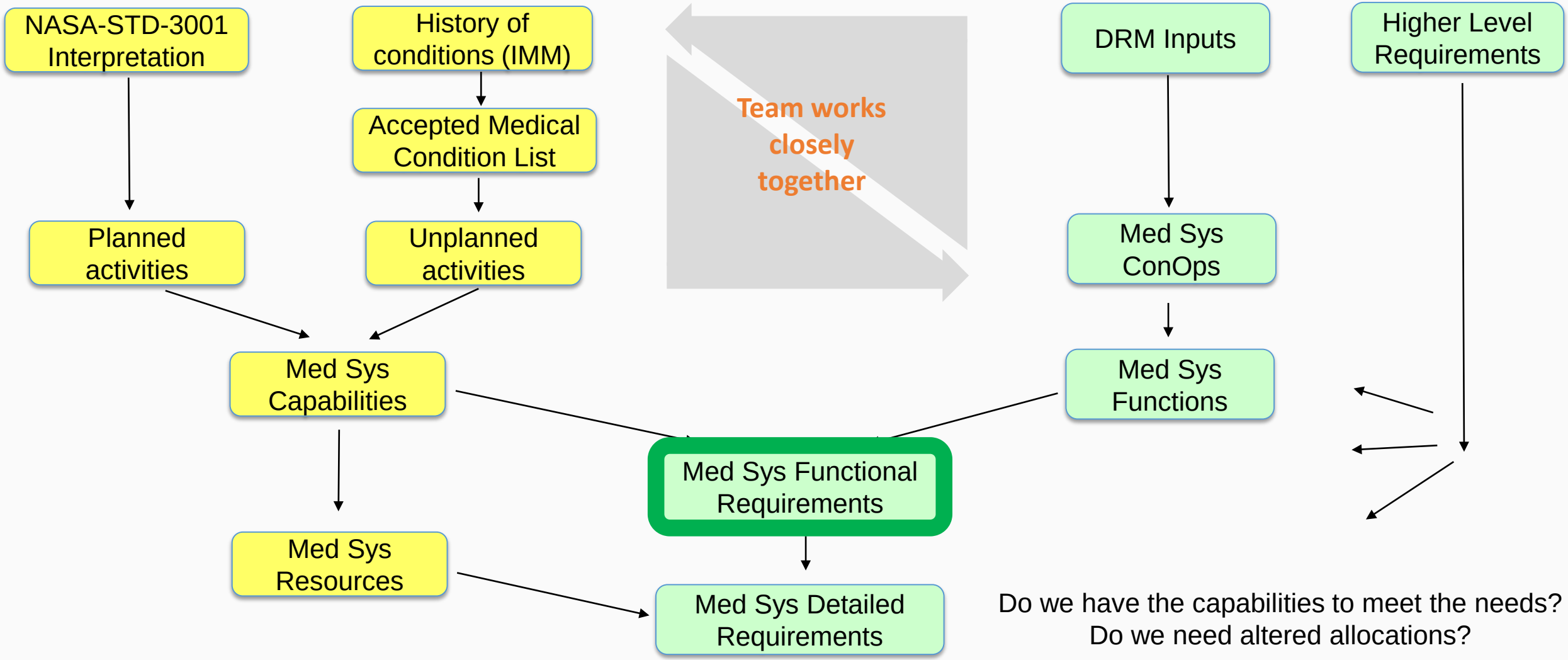
K. McGuire

[1]V. Braun, & V. Clark.. Using thematic analysis in psychology. Qualitative research in psychology, 3(2), 77-101. 2006.

Team activities to get to requirements

Medical Domain Activities

Sys Eng Activities



Do we have the capabilities to meet the needs?
Do we need altered allocations?

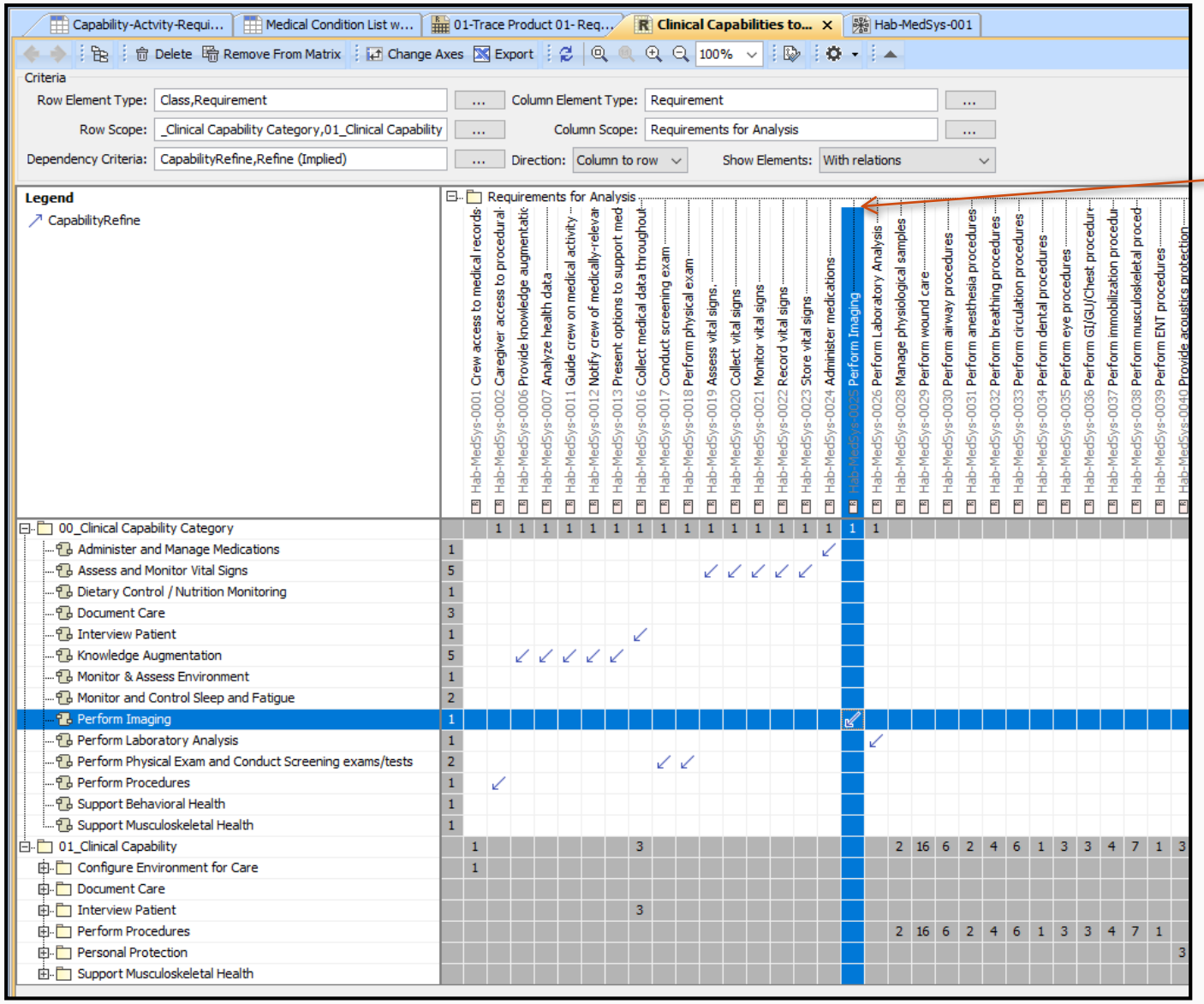
See IWS talk on the requirements development!

Outcome – Functional Requirements in these Categories

- **Provide Appropriate Level of Care**
- **Environment Configuration for Medical Care**
  - Configure Environment for Care
  - Habitat Medical Systems Inventory
- **Knowledge-Based Support for Crew Performing Medical Tasks**
  - Augment Crew Knowledge
  - Analyze Health Data
  - Data Presentation
  - Support Crew Performing Tasks
- **Crew**
  - Crew as Caregiver
  - Crew as Patient
  - Crew as Crewmember
- **Caregiver/Patient Interactions**
  - Interview Patient
  - Perform Physical Exam and Conduct Screening exams/tests
  - Assess and Monitor Vital Signs
  - Administer and Manage Medications
  - Perform Imaging
  - Perform Laboratory Analysis
  - Perform Procedures
  - Personal Protection
- **Medical Assessment and Monitoring**
  - Dietary Control/Nutrition Monitoring
  - Monitor and Assess Environment
  - Monitor and Control Sleep and Fatigue
  - Support Behavioral Health
  - Support Musculoskeletal Health
- **Maintaining Current State of Medical System**
  - Document Care
  - Update Habitat Medical System
  - Analyze Engineering Data
- **In-Flight Prevention**
  - Equipment Procedure
  - Exercise Protocol
  - Hygiene
  - Personal Protection
  - Radiation Exposure
  - Private Conference

Requirements relationships to discipline inputs

Input from clinicians - Capability Category: Perform Imaging

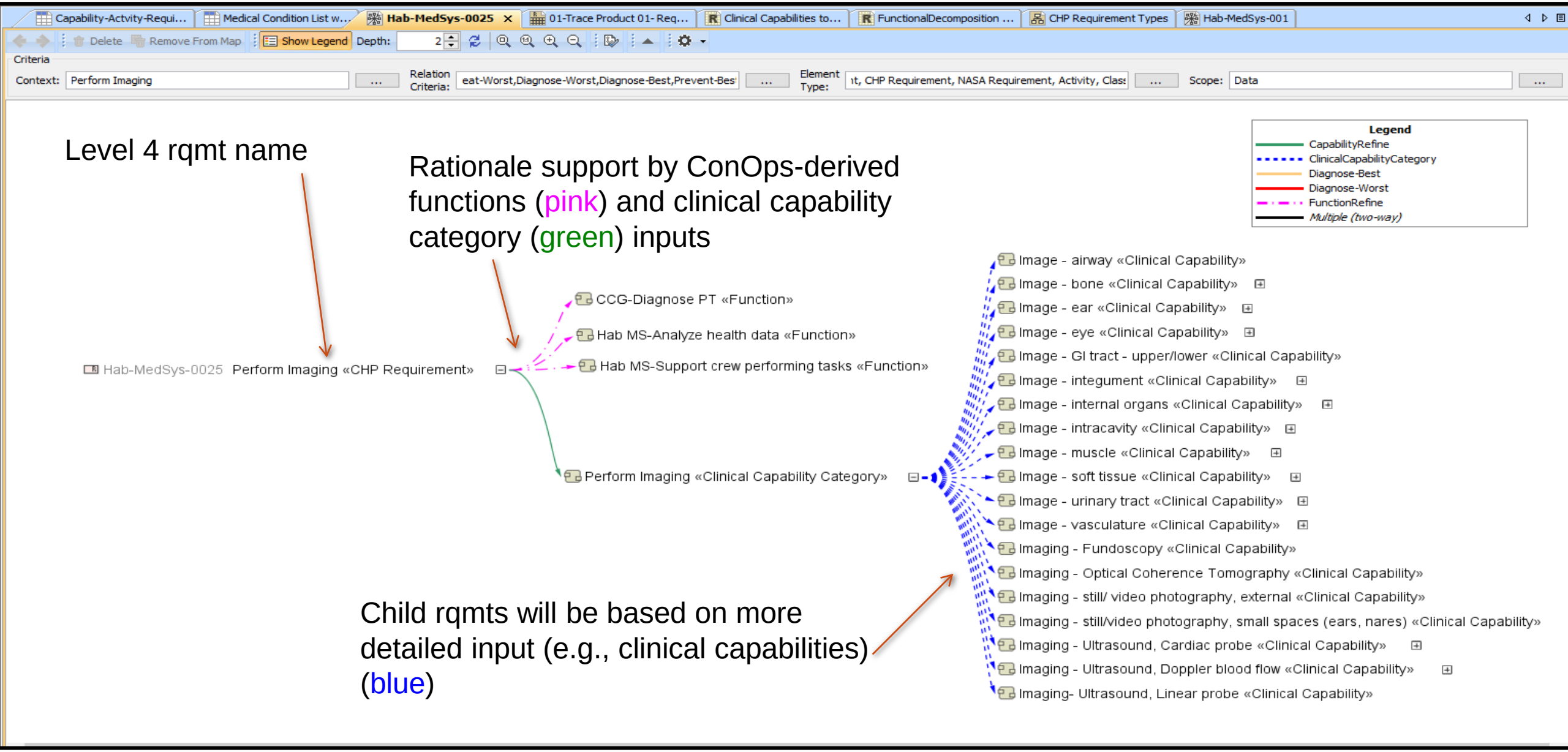


Output from Rqmts Team - Rqmt: Perform Imaging

Example question for current iteration:
Are the requirement text and rationale statements a reasonable reflection of intent for the related inputs?

This is building the bridge between SME content and engineering language!

Visualizing the requirement “legs to stand on”



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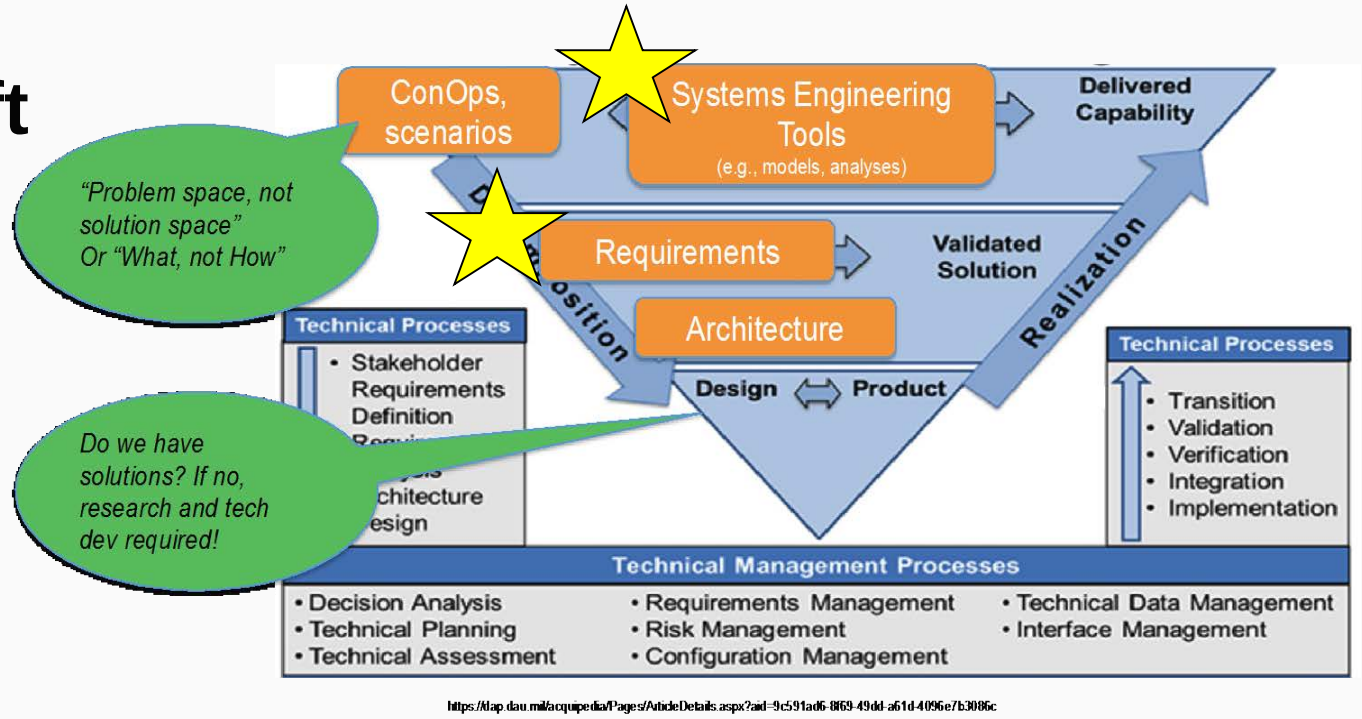

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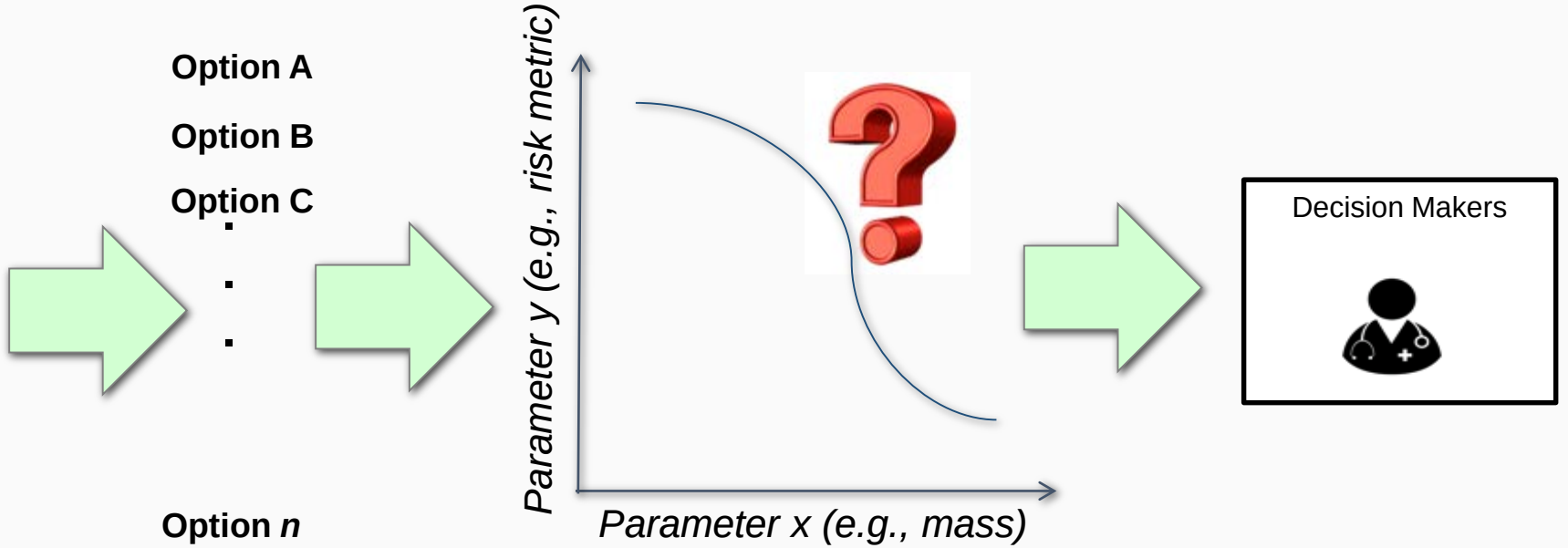
Trade Space Evaluation Tool Suite – Long-term Goals

- Characterize the exploration medical system architecture trade space to inform mission development, vehicle and habitat development, and research planning.
- For each trade option, characterize medical system parameters relevant to mission decision-makers (e.g., risk metrics, mass).

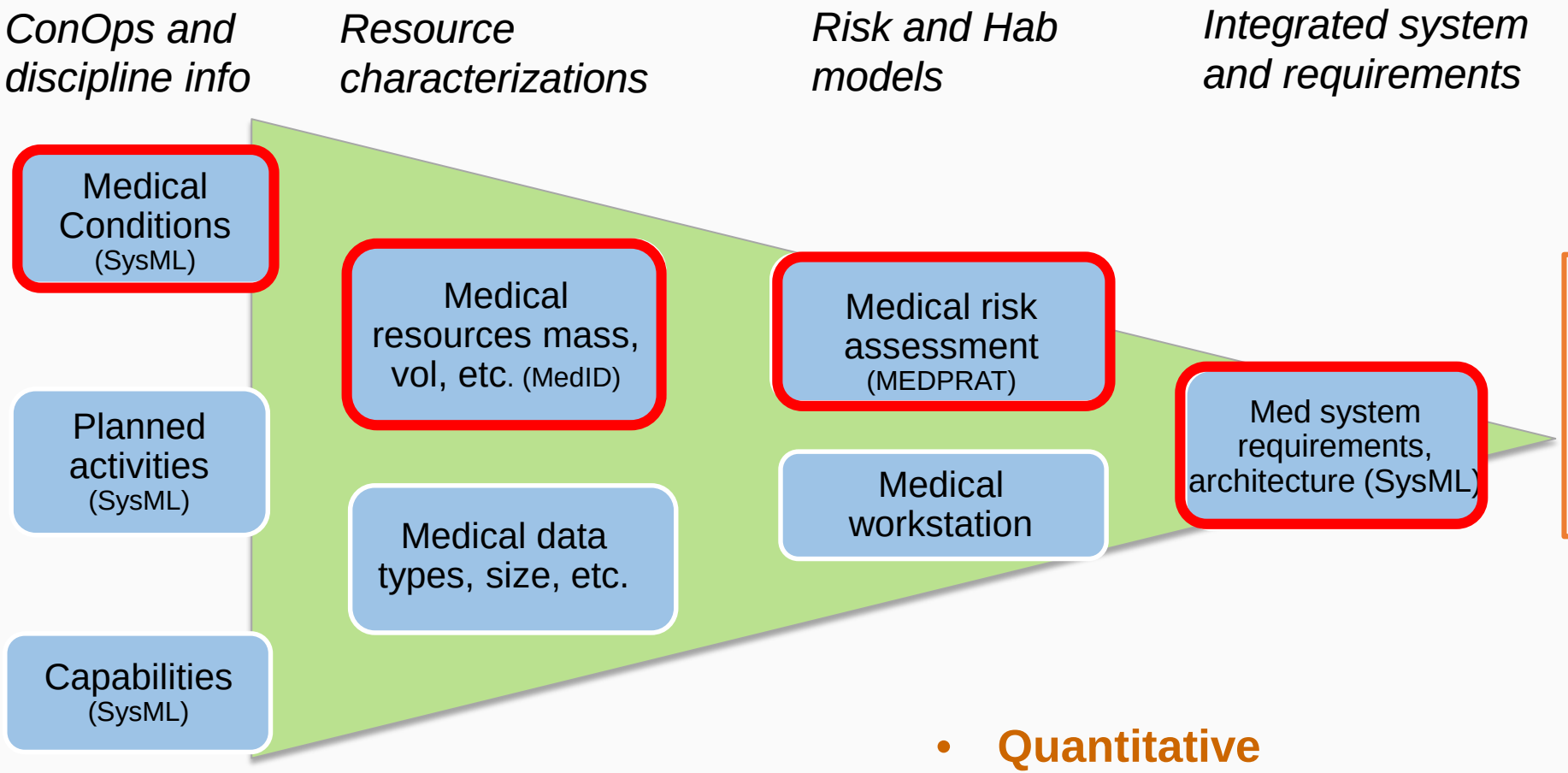
Trade Option Characterization

- Med conditions addressed
- Standards and rqmts met
- Master equipment list
- Risk evaluations
- Non-tech resources needed
- Med workstation characterized
- Data storage and processing defined
- Mission characteristics (crew size, duration)



- Pilot project performed practice assessment of 2 options for FY18
- Tied together multiple tools to produce cohesive assessment

Collaboration among tools



Trade Option Characterization

1) Med conditions addressed
2) Standards and rqmts met
3) Master equipment list generated
4) Risk evaluations
5) Non-tech resources needed
6) Med workstation characterized
7) Data storage and processing defined

- **Quantitative**
- **Systematic**
- **Repeatable**

Part of FY18 pilot project with representative info to establish tool interfaces

Produced consistent, integrated data

Sample system comparison summary table produced using multiple tools in collaboration

System Characteristic	System 1	System 2
Mass (kg)	115.2	115.0
Prob of Loss of Crew	0.0004	0.0004
Prob of EVAC	0.004	0.005
Crew Health Index	0.971	0.975
Requirements not met	0	3
Conditions not addressed	0	10

Representative data from tool suite practice runs Demonstrating tool interactions to produce cohesive summary

Sample detail that supports summary info

Analysis Results:	Trial A Run1	Trial A Run 2
1. Number of impacted medical conditions	0	10

Trial A Run 1 Impacted Conditions:

Trial A Run 2 Impacted Conditions:
Acute Cholecystitis/Biliary Colic
Acute Radiation Syndrome
Altitude Sickness
Appendicitis
Barotrauma (ear/sinus block)
Gastroenteritis
Head Injury
Indigestion
Nephrolithiasis
Space Motion Sickness (space adaptation)

In summary, ExMC has:

- Established a Systems Engineering team, processes, and products to integrate with exploration programs
- Built a bridge across medical and engineering domains
- Created a capability to provide traceable, defensible system development products

Backup

Why a New Paradigm for Exploration Medical?

- Crew health and performance (CHP) will have significantly greater impacts on mission risk than current operations have

- Deep space exploration missions present new challenges to crew health and performance:
  - Effects of hazards on crew health and performance are not completely known for long durations or deep space
  - Communication delays, blackout periods
  - No resupply, prepositioning at best
  - No medical evacuation

Deep space will be different…

- Gateway provides an opportunity to prepare for deeper exploration

- Limited flight resources (e.g., mass, power, volume, data) → view CHP as **an integrated part of flight system development**

- → We are applying systems engineering within HRP to better integrate with exploration offices that are in formulation

Canga, M., Shah, R., Mindock, J., Antonsen, E. A Strategic Approach to Medical Care for Exploration Missions. 67th International Astronautical Congress (IAC), Guadalajara, Mexico, Sept. 2016
Antonsen, E., Hanson, A., Shah, R., Reed, R., Canga, M. Conceptual Drivers for an Exploration Medical System. 67th International Astronautical Congress (IAC), Guadalajara, Mexico, Sept. 2016

ExMC Systems Engineering – Accomplishments since last IWS

- **Medical System Functional Requirements (HRP OMB milestone)**
  - Completed Recommended Draft Medical System Functional Requirements for Gateway
  - ✓ **Provides foundation for integration with exploration missions**
  - ✓ **Bridged clinical and engineering communities!!**
- **Concepts of Operations**
  - Completed Level 4 Recommended Medical System Concept of Operations for Gateway
  - Completed Level 2 Human Systems Integration Concept of Operations for Gateway
  - Completed first draft of Level 4 Crew Health and Performance System Concept of Operations for Gateway
  - ✓ **Provides system vision, architecture, scenario content informing requirements**
- **Crew Health and Performance System for Gateway**
  - Recommendation agreed among HRP, Human Health & Performance Directorate, and Health & Medical Tech Authority
  - ✓ **Enables integrated system to prevent stove-piped solutions**
- **Trade Study Tools Pilot Project**
  - Met success criteria – produced output of system characteristics coordinated among MEDPRAT, MedID, and SysML model
  - ✓ **Allows quantitative, repeatable, self-consistent analyses of system options**
- **Historical requirements analysis initiated – informed requirements**
  - 3001, ISS PRVD, ISS MORD
  - ✓ **Establishes capability to compare to past systems and build on lessons learned**
- **Applying MBSE**
  - Model maturity increased – trace products created to inform requirements development
  - ✓ **Applies the power of relationships in our model**
- **Other –** Well attended IWS 2018, MBSE training, MBSE community participation (NASA-wide and Centers), IEEE 2019 conference paper

Example Scenario - Headache

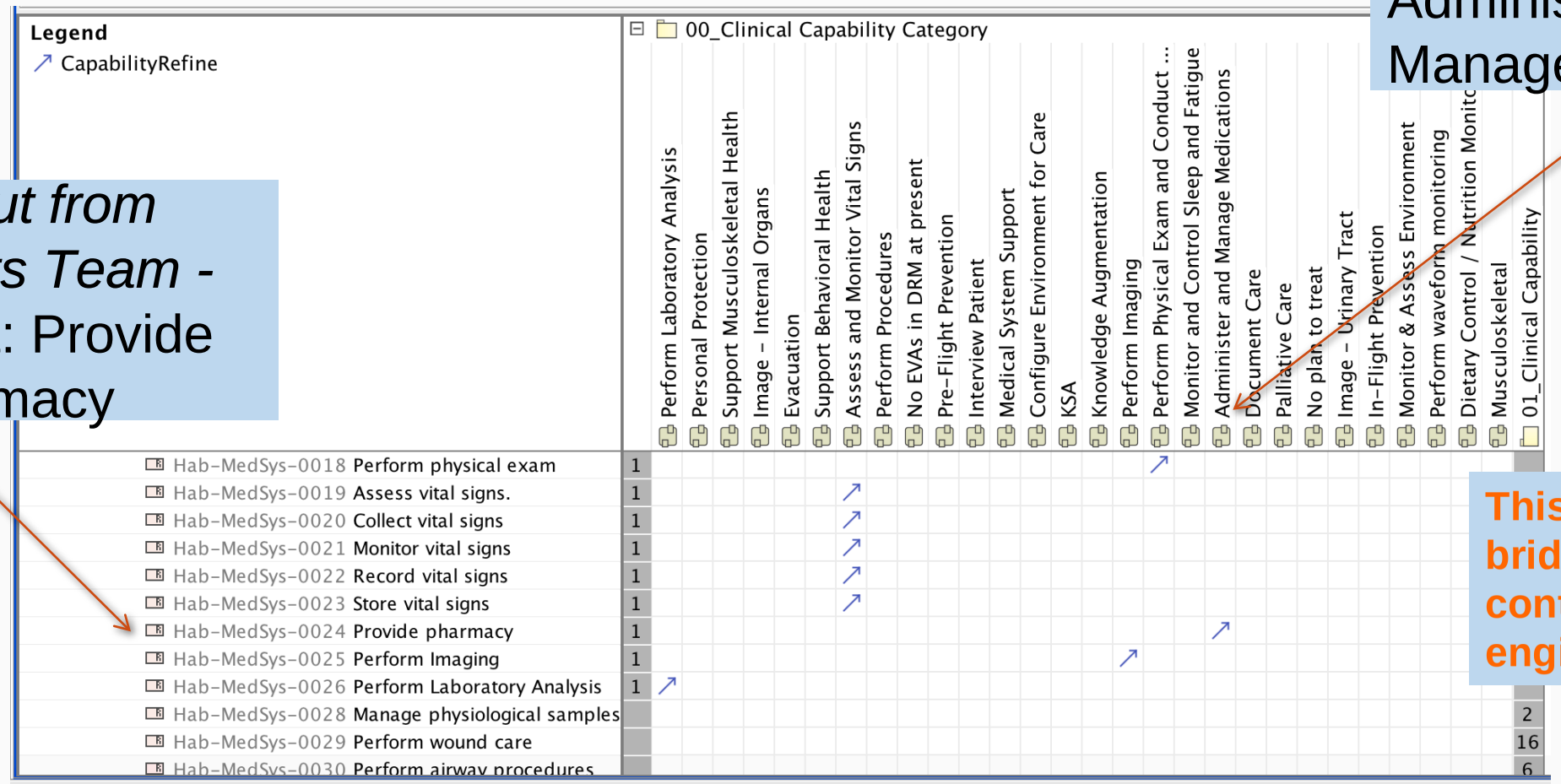
This scenario shows that the medical system can:

a) Prompt and facilitate data collection for unplanned medical events.
b) Receive data entry from the patient about the patient.
c) Provide limited decision support for self-care conditions.
d) Assess known inventory and report stowage locations to crew via the Gateway Habitat Medical System interface.
e) Automatically report inventory status to the Ground Medical System.
f) Generate alerts for the Ground Medical System based upon inflight interactions with the system.
g) Record and transmit medically oriented, attributable information to ground clinicians.
h) Retrieve reports in the Ground System that can be reviewed by the Gateway Habitat Medical System

Requirements relationships to discipline inputs

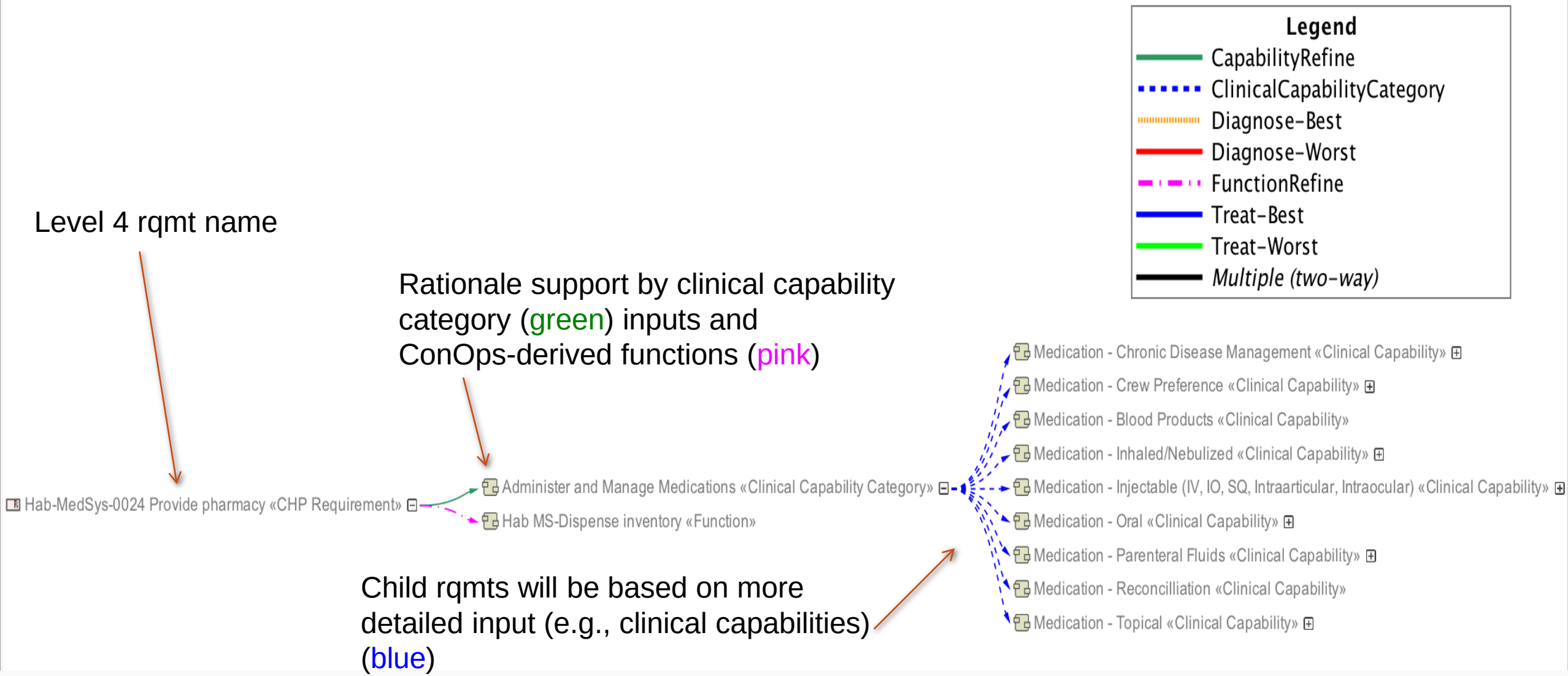
Input from clinicians - Capability Category: Administer and Manage Medications

Output from Rqmts Team - Rqmt: Provide Pharmacy

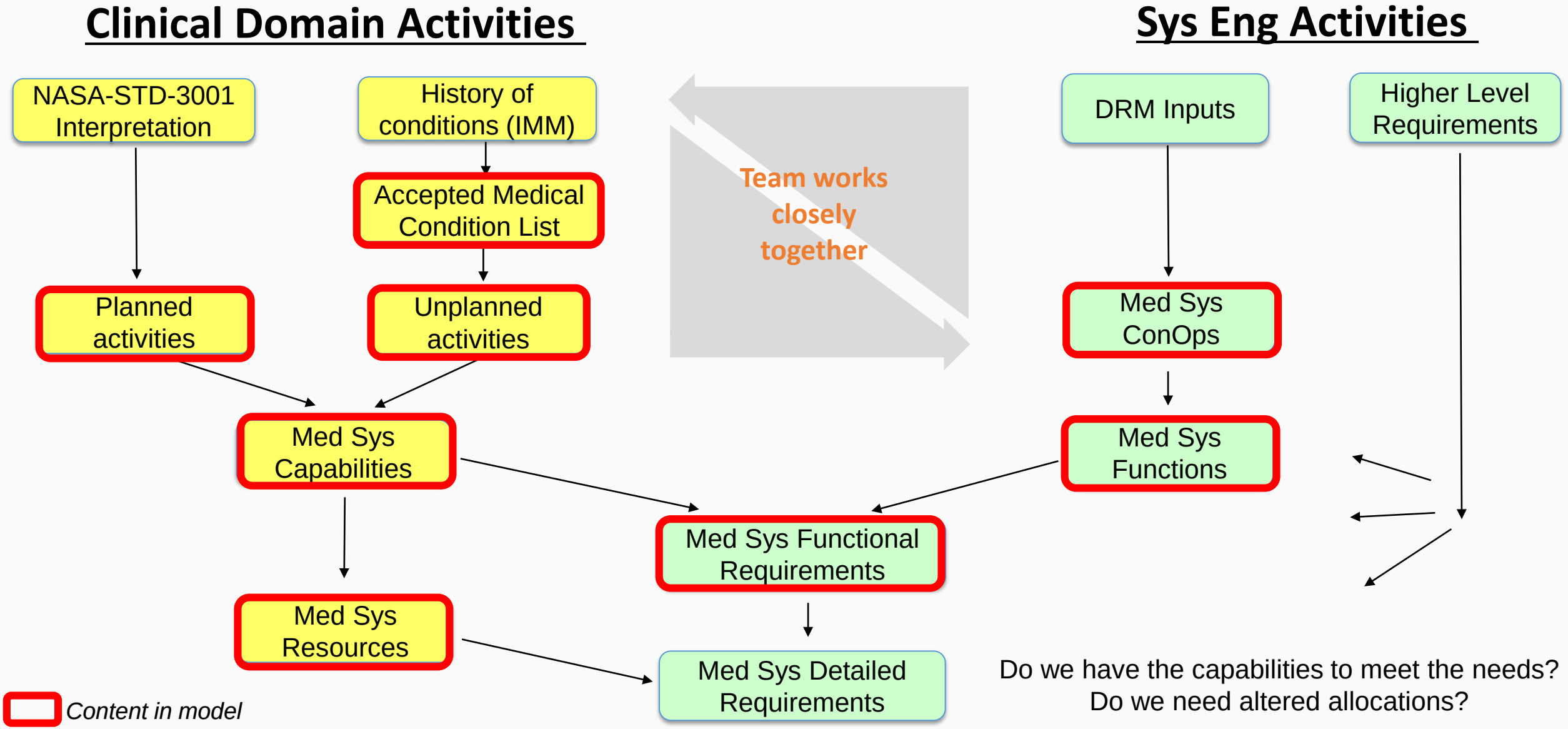


This is building the bridge between SME content and engineering language!

Visualizing the requirement “legs to stand on”



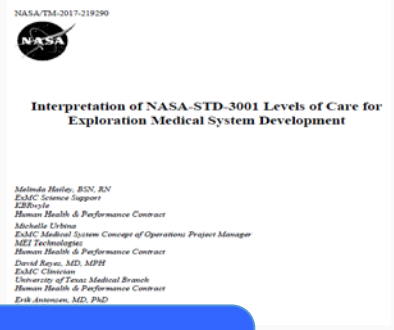
Team activities to get to requirements



Approach to Get There

Stakeholder needs, goals

NASA Standards


NASA/TM-2017-219290

Interpretation of NASA-STD-3001 Levels of Care for Exploration Medical System Development

Melinda Hatley, BSN, RN
ExMC Science Support
KBRwyle
Human Health & Performance Contract

Michelle Urbina
ExMC Medical System Concept of Operations Project Manager
MEI Technologies
Human Health & Performance Contract

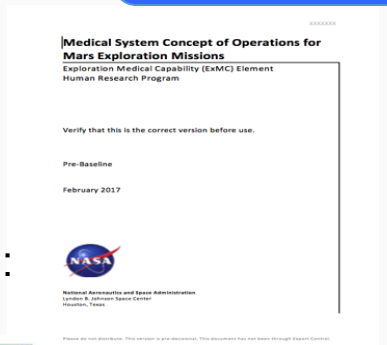
David Reyes, MD, MPH
ExMC Clinician
University of Texas Medical Branch
Human Health & Performance Contract

Erik Antonsen, MD, PhD

Program requirements & architecture

System functions & behaviors

Began with Mars transit to develop body of work and used that infrastructure for Gateway-relevant content in FY18 and now FY19.


Medical System Concept of Operations for Mars Exploration Missions

Exploration Medical Capability (ExMC) Element
Human Research Program

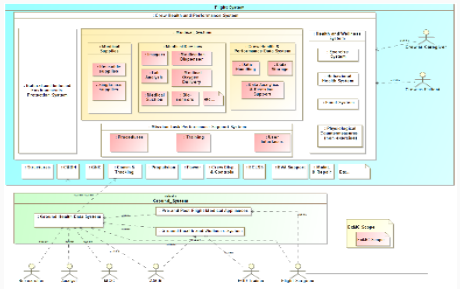
Verify that this is the correct version before use.

Pre-Baseline

February 2017

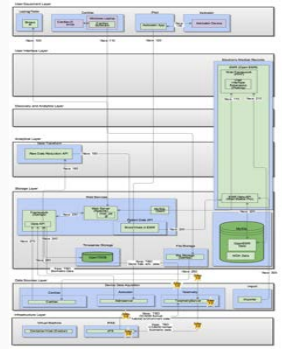
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas

System requirements & architecture

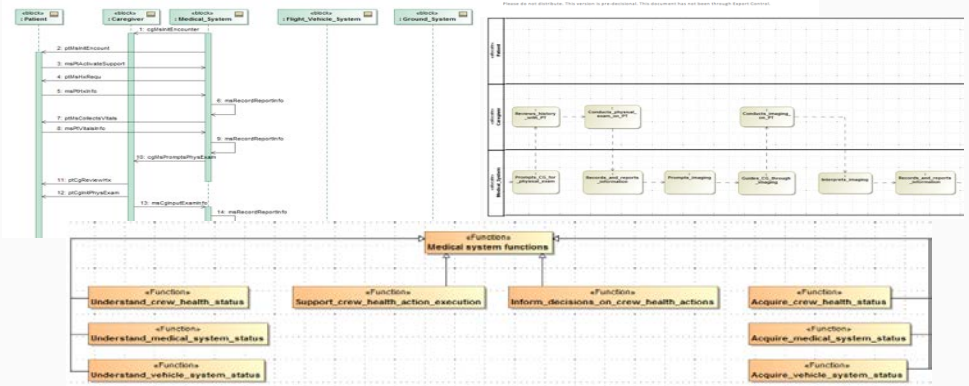


Using Model-Based Systems Engineering:

Subsystem requirements & architecture

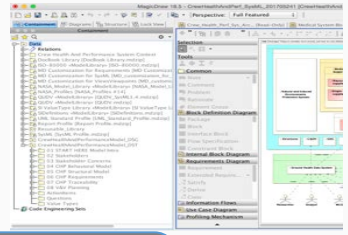


Characterize system



Do we have the capabilities to meet the needs?
Do we need altered allocations?

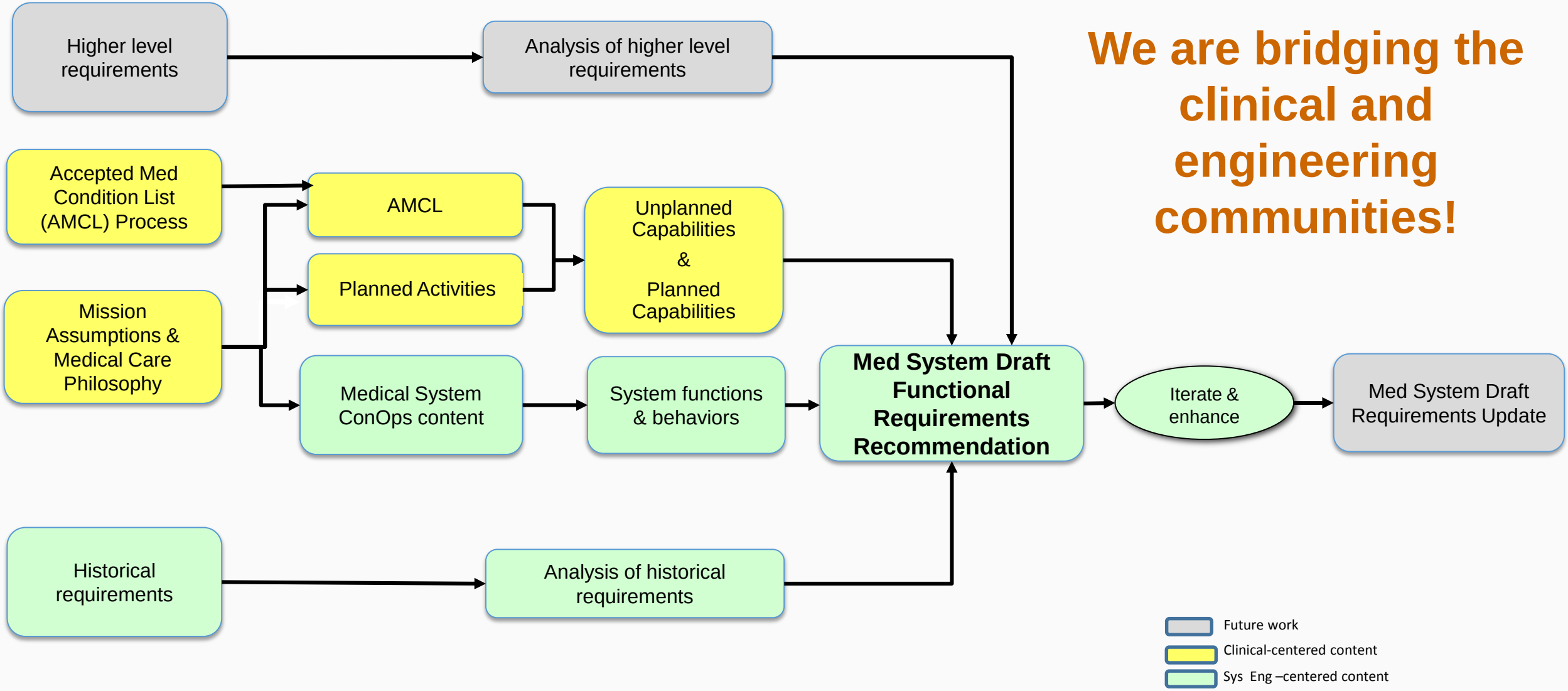
Analyze & trade



Design & Build

The needs identified by this work will drive future ExMC research

Team activities

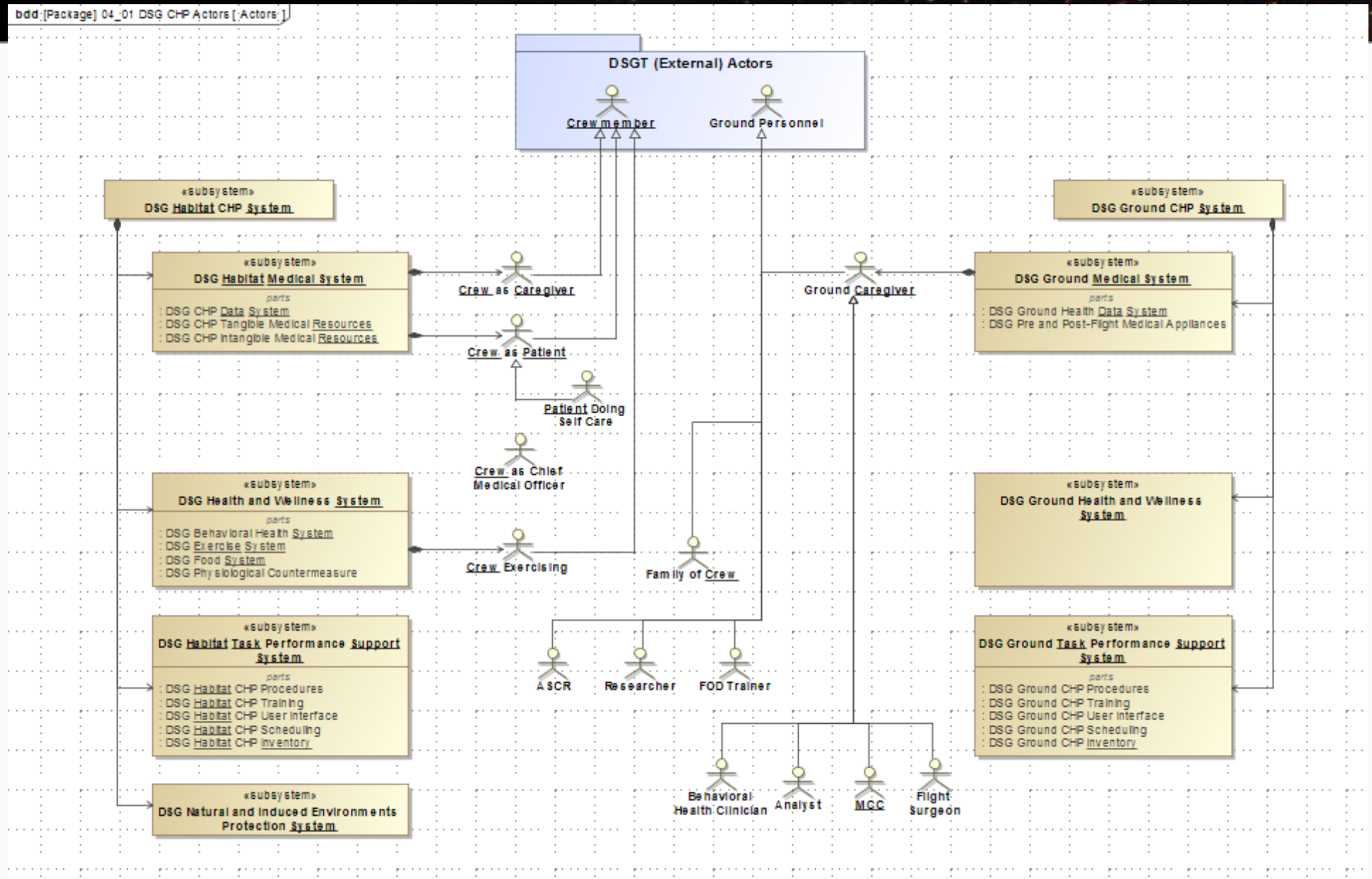


We are bridging the clinical and engineering communities!

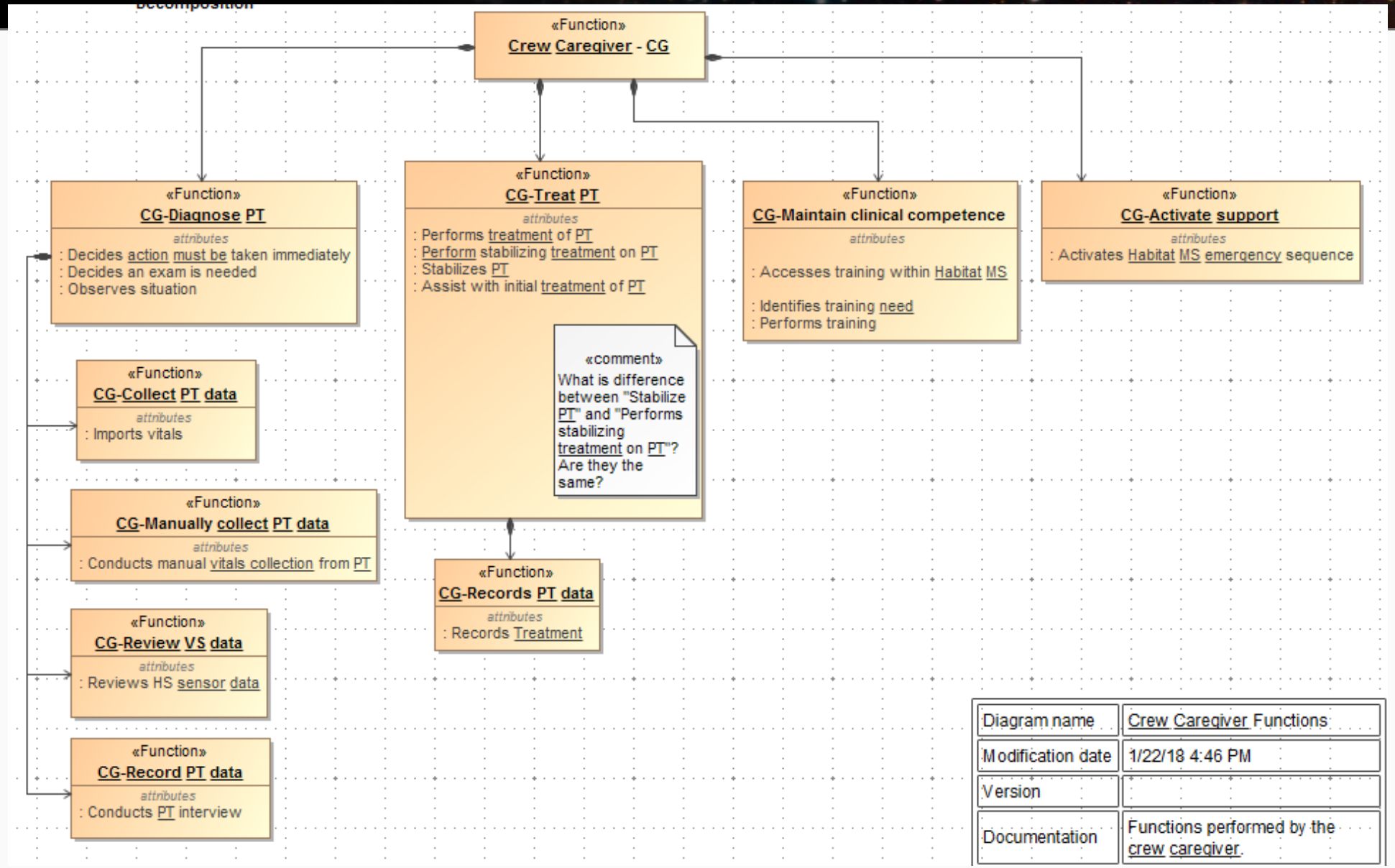
Requirement Examples

ID	Name	Text	Rationale
Hab-MedSys-0024	Provide pharmacy	The Habitat Medical System shall provide an in-flight pharmacy to the crew members.	Pharmaceutical intervention and prevention, as provided by the in-flight pharmacy, is an essential component of risk management planning for crew healthcare during spaceflight. This includes prepare, administer, document, monitoring, inventory, analyze efficacy of med, titrate, or choose new medication if needed. Pharmaceutics assist crewmembers with adaptation to the spaceflight environment as well as help manage unexpected medical events that could occur, such as illness or injury. Types of medications needed are specified at Level 5.
Hab-MedSys-0005	Track medical inventory	The Habitat Medical System shall track medical inventory.	Ensure that medical inventory (supplies, equipment, and medications) is tracked at all times including when inventory is dispensed. Specific medical inventories, including quantities, availability, track history, etc., are specified at Level 5.
Hab-MedSys-0204	Perform genitourinary procedures	The Habitat Medical System shall enable caregivers to perform genitourinary procedures.	The medical system needs to provide capabilities (e.g., tools, technology, skills, medications) to perform genitourinary (GU) procedures (such as decompression of bladder). These procedures are needed for treatment of conditions such as urinary retention. Types of GU procedures are specified at Level 5.

Actors


bdd [Package] 04_01 DSG CHP Actors [Actors]
DSGT (External) Actors
Crew member
Ground Personnel
«subsystem»
DSG Habitat CHP System
«subsystem»
DSG Habitat Medical System
parts
: DSG CHP Data System
: DSG CHP Tangible Medical Resources
: DSG CHP Intangible Medical Resources
Crew as Caregiver
Crew as Patient
Patient Doing Self Care
Crew as Chief Medical Officer
«subsystem»
DSG Health and Wellness System
parts
: DSG Behavioral Health System
: DSG Exercise System
: DSG Food System
: DSG Physiological Countermeasure
Crew Exercising
Family of Crew
«subsystem»
DSG Habitat Task Performance Support System
parts
: DSG Habitat CHP Procedures
: DSG Habitat CHP Training
: DSG Habitat CHP User Interface
: DSG Habitat CHP Scheduling
: DSG Habitat CHP Inventory
«subsystem»
DSG Natural and Induced Environments Protection System
ASCR
Researcher
FOD Trainer
«subsystem»
DSG Ground CHP System
Ground Caregiver
«subsystem»
DSG Ground Medical System
parts
: DSG Ground Health Data System
: DSG Pre and Post-Flight Medical Appliances
«subsystem»
DSG Ground Health and Wellness System
«subsystem»
DSG Ground Task Performance Support System
parts
: DSG Ground CHP Procedures
: DSG Ground CHP Training
: DSG Ground CHP User Interface
: DSG Ground CHP Scheduling
: DSG Ground CHP Inventory
Behavioral Health Clinician
Analyst
MCC
Flight Surgeon

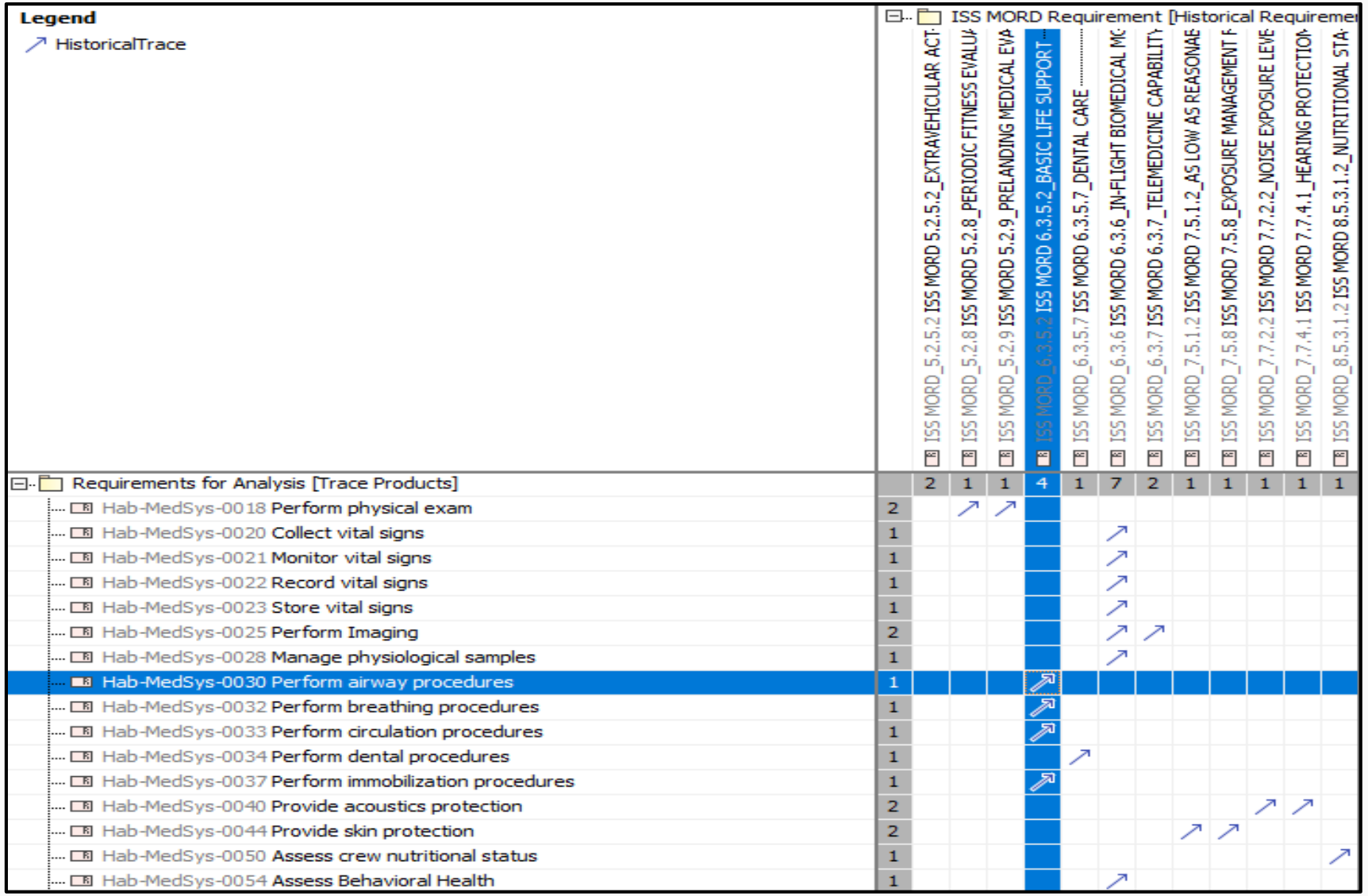
Crew Caregiver Functions



MBSE – capture relationships to past Programs

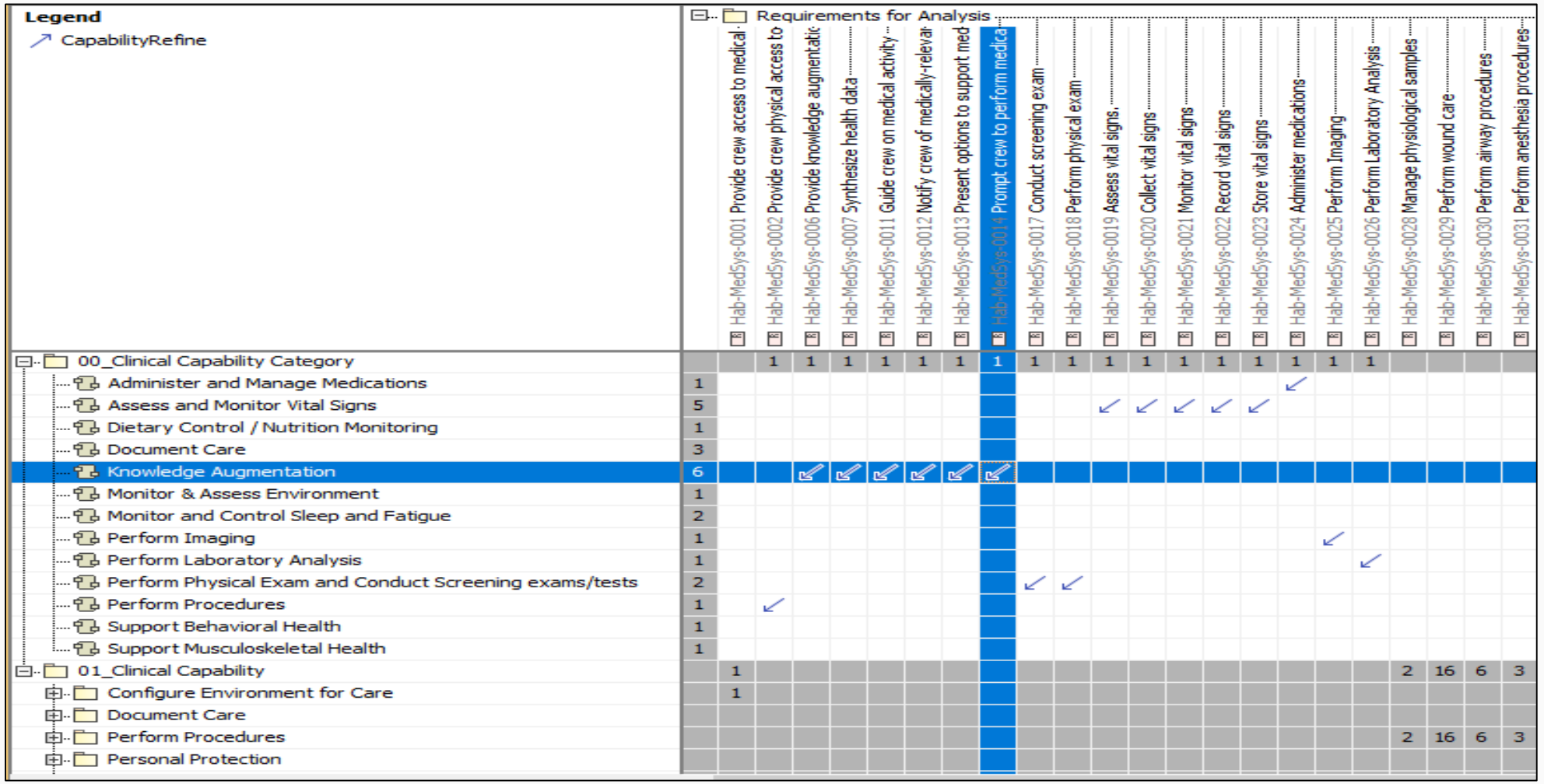
Historical rqmts

Current rqmts in development

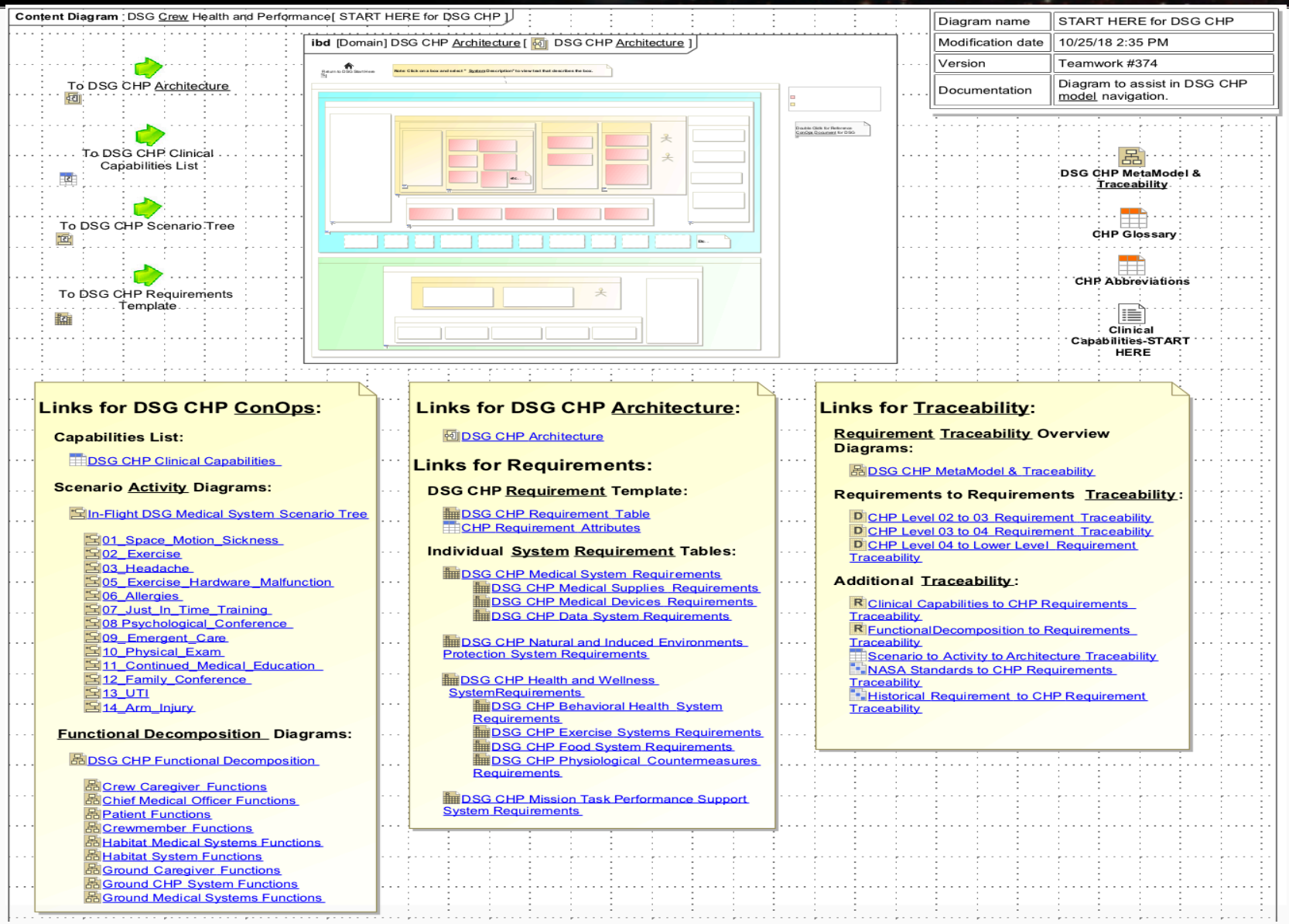


Are we missing anything in our new set that we've had in the past?

Capabilities to Requirements



MBSE – Pulling Systems Engineering Work Together



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Requirements relationships to functions from ConOps